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The Role of Geomatics in Supporting Sustainable Development Policy-making

By

Aining Zhang, B. Eng., M. Eng., M. A.

**A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of**

Doctor of Philosophy

**Department of Geography and Environmental Studies
Carleton University
Ottawa, Ontario**

May 2000

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Acceptance Form

The undersigned recommend to the Faculty of Graduate Studies acceptance of the thesis,

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submitted by

Aining Zhang, B.Eng., M. Eng., M.A.

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy.

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Carleton University

May 2000

Abstract

Sustainable development has been on national policy agendas since 1992 when Agenda 21, an international agreement on sustainable development, was signed by over 150 countries. A key to sustainable development policy-making is information. Spatial information is an integral part of this information pool given the spatial nature of sustainable development. Geomatics, a technology dealing specifically with spatial information, can play a major role in support of the policy-making process. This thesis is aimed at advancing this role.

The thesis starts with a discussion of theories and methodologies for sustainable development. The policy process for sustainable development is characterized, followed by an analysis of the requirements of sustainable development policy-making for geomatics support. The current status of geomatics in meeting these requirements is then examined, and the challenges and potential for geomatics to further address the needs are identified. To deal with these challenges, an integrated solution, namely the development of an on-line national policy atlas for sustainable development, is proposed, with a focus to support policy action formulation.

The thesis further addresses one of the major research topics required for the implementation of the proposed solution, namely the exploration of the feasibility of a spatial statistics approach to predictive modelling in support of policy scenario assessments. The study is based on the case of national climate change policy formulation, with a focus on the development of new light duty vehicle sales mix models in support of transportation fuel efficiency policy-making aimed at greenhouse gas reductions. The conceptual framework and methodology for the case study are followed by the presentation of outcomes including models and policy scenario forecasts. The case study has illustrated that a spatial statistics approach is not only feasible for the development of predictive models in support of policy-making, but also provides several unique advantages that could potentially improve sustainable development policy-making.

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Table of Contents

ACCEPTANCE FORM	II
ABSTRACT	III
ACKNOWLEDGEMENTS	IV
TABLE OF CONTENTS	VI
LIST OF TABLES.....	XI
LIST OF FIGURES.....	XII
LIST OF CHARTS.....	XIII
LIST OF MAPS	XIV
LIST OF APPENDICES.....	XV
LIST OF ACRONYMS	XVI

CHAPTER 1

INTRODUCTION	1
1.1 <i>Origin of the Topic</i>	1
1.2 <i>Objectives</i>	4
1.3 <i>Areas of Concern</i>	5
1.3.1 <i>Sustainable Development</i>	6
1.3.2 <i>Policy Science</i>	7
1.3.3 <i>Climate Change</i>	7
1.3.4 <i>Geomatics</i>	8
1.3.5 <i>Energy Modelling and Vehicle Market Research</i>	8
1.3.6 <i>Business Intelligence Technology</i>	9
1.4 <i>Research Methodologies</i>	9
1.5 <i>Thesis Structure</i>	12

PART I

ENVIRONMENTAL CHOICES FOR SUSTAINABLE DEVELOPMENT: THEORY AND METHODOLOGY	14
--	----

INTRODUCTION TO PART I	14
------------------------------	----

CHAPTER 2

CAUSES OF THE ENVIRONMENTAL CRISIS	16
2.1 <i>Environmentally-detrimental Mode of Production</i>	16
2.2 <i>Over-population</i>	18
2.3 <i>Poverty</i>	19
2.4 <i>Resource Over Consumption</i>	21

2.4.1	Inefficient Resource Consumption as Lifestyle.....	21
2.4.2	Economic Growth as A Developmental Strategy.....	22
2.4.3	Industrial Competitive Materialism as Social Value.....	23
CHAPTER 3		
A BRIEF REVIEW OF MAJOR APPROACHES TO ENVIRONMENTAL SUSTAINABILITY		25
3.1	<i>Cornucopian</i>	25
3.2	<i>Mainstream Approach</i>	27
3.2.1	A Brief Overview.....	28
3.2.2	Strengths and Weakness.....	35
3.3	<i>Social Ecology</i>	39
3.3.1	A Brief Overview.....	39
3.3.2	Strength and Weakness	45
3.4	<i>Deep Ecology</i>	48
3.4.1	A Brief Overview.....	49
3.4.2	Strength and Weakness	51
CHAPTER 4		
TOWARDS AN INTEGRATION OF REDUCTIONIST AND HOLISTIC APPROACHES		54
4.1	<i>From Materialism to Organism - A Holistic Worldview</i>	55
4.2	<i>From Individualism to Individual-in-Community - The Emerging Ethics, Values and Political Ideology</i>	58
4.3	<i>From Chrematistics to Oikonomia - A Quest for An Economic System</i>	63
4.4	<i>Institutional Reform - Searching for A Holistic Framework</i>	69
4.5	<i>From Reductionist Science to Holistic Science - The Emerging Scientific Paradigm</i>	71
CONCLUSIONS OF PART I.....		76
PART II		
ROLE OF GEOMATICS IN SUSTAINABLE DEVELOPMENT POLICY-MAKING		79
INTRODUCTION TO PART II.....		79
CHAPTER 5		
SUSTAINABILITY POLICY PROCESS AND POLICY-MAKING: THE CASE OF CLIMATE CHANGE.....		81
5.1	<i>Problem Identification</i>	82
5.2	<i>Agenda Setting</i>	85
5.3	<i>Policy Goal Formulation</i>	86
5.4	<i>Policy Action Formulation</i>	88
5.5	<i>Policy Implementation</i>	90
5.6	<i>Monitoring and Evaluation</i>	91
CHAPTER 6		
CHARACTERISTICS AND CHALLENGES OF SUSTAINABLE DEVELOPMENT POLICY-MAKING IN RELATION TO GEOGRAPHICAL SPACE.....		93
6.1	<i>Broadness and Integrativeness</i>	93
6.2	<i>Spatial Dynamics</i>	95
6.2.1	Spatial Diversity.....	96
6.2.2	Spatial Scale.....	97
6.2.3	Spatial Processes.....	100

6.3	<i>Participatory Democracy</i>	101
CHAPTER 7		
CURRENT ROLE OF GEOMATICS IN SUPPORT OF SUSTAINABILITY POLICY-MAKING.....		103
7.1	<i>Remote Sensing Complemented with Global Positioning Systems – A Unique Approach to Global Monitoring</i>	104
7.1.1	Resource and Environmental Data Acquisition.....	104
7.1.2	Framework Data Acquisition	109
7.2	<i>GIS - The Unique technology for Geospatial Data Integration, Analysis and Communication</i>	109
7.2.1	Data Integration	110
7.2.2	Analysis of Spatial Dynamics	111
7.2.3	Visualization of Spatial Phenomena.....	112
7.3	<i>Geomatics Technology for Spatial Data Access and Delivery</i>	113
CHAPTER 8		
CHALLENGES AND OPPORTUNITIES OF GEOMATICS IN SUPPORT OF SUSTAINABILITY POLICY-MAKING		115
8.1	<i>The Data Issues</i>	115
8.1.1	Need for More Data	115
8.1.2	Data Accessibility	116
8.1.3	Data Compatibility	117
8.2	<i>GIS for Sustainability Problem Identification</i>	119
8.2.1	Data Model	119
8.2.2	Quantitative Modelling Environment.....	121
8.2.3	Scientific Visualization	122
8.3	<i>Geomatics in Support of Policy Action Formulation</i>	124
8.3.1	GIS for Quantitative Assessment of Policy Options	125
8.3.2	Access to Sustainability Information in the Consultation Process	126
8.3.3	Geomatics in Support of Policy Decision Making	127
8.4	<i>Conceptual Issues of GIS in Support of Sustainability Policy-making</i>	130
CHAPTER 9		
TOWARDS AN INTEGRATED SOLUTION TO SUPPORTING NATIONAL POLICY ACTION FORMULATION: AN ON-LINE NATIONAL POLICY ATLAS FOR SUSTAINABLE DEVELOPMENT.....		133
9.1	<i>Purposes of the On-line National Policy Atlas (ONPA)</i>	133
9.2	<i>A Conceptual Model of the ONPA</i>	135
9.2.1	Content Model	136
9.2.2	Functionality Model.....	137
9.3	<i>Rationale</i>	142
9.4	<i>Current Status of Knowledge and Technology for Implementing ONPA</i>	147
9.5	<i>R&D Required for ONPA Implementation</i>	147
CONCLUSIONS OF PART II		152
PART III		
A SPATIAL STATISTICS APPROACH TO PREDICTIVE MODELLING SUPPORTING CLIMATE CHANGE POLICY ASSESSMENT: THE CASE OF NEW LIGHT DUTY VEHICLE SALES MIX AND AVERAGE FUEL INTENSITY		156
INTRODUCTION TO PART III		156

CHAPTER 10

CONTEXT OF THE CASE STUDY	158
10.1 <i>Canada's Efforts on Climate Change</i>	158
10.2 <i>Dealing with the Kyoto Challenge</i>	159
10.3 <i>The Transportation Sector</i>	161
10.4 <i>Recent Studies on Transportation Policy Measures</i>	163
10.5 <i>The Rationale of A Spatial Statistics Approach to New LDV Sales Mix Modelling</i>	167

CHAPTER 11

OBJECTIVES OF THE CASE STUDY	172
11.1 <i>The Exploration of the Feasibility of A Spatial Approach to Predictive Modelling in Support of Policy Scenario Assessments</i>	172
11.2 <i>To Develop Spatially-based New LDV Sales Mix Models at the Levels of Disaggregation Required for Policy-making</i>	174
11.3 <i>To Test and Showcase the Capability of the Spatially-based New LDV Sales Mix Models for Policy Scenario Forecast</i>	174

CHAPTER 12

A CONCEPTUAL FRAMEWORK	176
12.1 <i>Construction of Spatial Data Samples</i>	176
12.2 <i>General Specifications of Spatial Econometric (Regression) Models</i>	177
12.2.1 <i>Concepts of Spatial Effects</i>	177
12.2.2 <i>Forms of Spatial Regression Models</i>	178
12.3 <i>Choice of Predicted Variables</i>	181
12.4 <i>Choice of Predictor variables</i>	182
12.4.1 <i>Predictor variables for LDV Market share Models</i>	182
12.4.2 <i>Predictor variables for New LDV Sales Model</i>	186
12.4.3 <i>Special Considerations for Policy Assessments</i>	186
12.5 <i>The Logistics of Modelling and Forecasting</i>	188

CHAPTER 13

VARIABLE DEFINITIONS AND DATA PROCESSING	192
13.1 <i>Predicted Variables</i>	192
13.1.1 <i>Market share of New Light Duty Vehicle by Size Class</i>	192
13.1.2 <i>Average New LDV Fuel Intensity</i>	194
13.2 <i>Predictor variables</i>	196
13.2.1 <i>Previous Year's New LDV Market share by Census Division</i>	196
13.2.2 <i>Relative Vehicle Purchase and Fueling Cost</i>	198
13.2.3 <i>Total Number of Household</i>	200
13.2.4 <i>Average Household Income</i>	201
13.2.5 <i>Population Age Group</i>	201
13.2.6 <i>Occupation</i>	202
13.2.7 <i>Population Density</i>	203
13.2.8 <i>Vehicle Stock</i>	203
13.2.9 <i>New Vehicle Affordability Indicator</i>	204
13.2.10 <i>Transit Vehicle Hours Serviced</i>	205
13.2.11 <i>Other Variables</i>	206

CHAPTER 14

METHODOLOGY FOR MODEL BUILDING AND FORECASTING	207
14.1 <i>Spatial Data Integration</i>	208
14.2 <i>Spatial Exploratory Data Analysis</i>	209
14.3 <i>Model fitting</i>	210
14.3.1 <i>Dealing with Spatial Heterogeneity</i>	210
14.3.2 <i>Dealing with Spatial Dependence</i>	215
14.3.3 <i>Improving Goodness-of-fit</i>	217

14.3.4	Special Treatment for Policy Variables.....	218
14.3.5	Other Issues.....	218
14.4	Model Validation.....	219
14.4.1	Confirmation of Correct Model Specification.....	220
14.4.2	Model Selection.....	220
14.4.3	Model Verification via Forecast.....	222
14.5	Forecasting.....	223
14.5.1	Forecasting of New LDV Market share by Census Division.....	224
14.5.2	Forecasting of New LDV sales by Census Division.....	226
CHAPTER 15		
NEW LDV MARKET SHARE AND SALES MODELS.....		228
15.1	The Market Share Model for Subcompact Cars.....	229
15.2	The Market Share Model for New Compact Cars.....	230
15.3	The Market Share Model for New Mid Size Cars.....	231
15.4	The Market Share Model of New Large Size Cars.....	231
15.5	The Market Share Model for New Small Pickup Trucks.....	232
15.6	The Market Share Model for New Small Vans.....	233
15.7	The Market Share Model for New Small Utilities.....	234
15.8	The Market Share Model for New Large Pickup Trucks.....	235
15.9	The Market Share Models for Other LDV Classes.....	236
15.10	New LDV Sales Model.....	238
CHAPTER 16		
A BUSINESS-AS-USUAL FORECAST OF NEW LDV MARKET SHARE, SALES, AND AVERAGE FUEL INTENSITY.....		240
16.1	Forecast of New LDV Sales Shifts and Average Fuel Intensity for Canada.....	240
16.2	New LDV Sales Shifts and Average Fuel Intensity by Province.....	248
16.3	Forecast of New LDV Sales Shifts and Average Fuel Intensity by Census Division.....	253
16.4	Forecast Verification.....	276
16.5	Forecast Calibration.....	280
16.6	The Validity of Spatial Econometric Models for Forecasting: A Brief Discussion.....	282
CHAPTER 17		
POLICY SCENARIO FORECAST: GASOLINE TAX INCREASES.....		285
SUMMARY AND CONCLUSIONS OF PART III		
New LDV Sales Mix Models and Their Characteristics.....		289
Major Determinants to New LDV Sales Mix.....		290
Forecast of New LDV Sales Mix Shift and Average LDV Fuel Intensity: the Business-as-usual and Fuel Tax Increase Scenarios.....		291
Regional Differences in New LDV Sales Mix, Average Fuel Intensity, and Their Trends.....		294
General Conclusions.....		296
CHAPTER 18.....		
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH.....		298
REFERENCES.....		
MAPS OF NEW LDV MARKET SHARE AND AVERAGE FUEL INTENSITY.....		304
		336

List of Tables

TABLE 3-1:	MAJOR APPROACHES TO ENVIRONMENTAL SUSTAINABILITY	26
TABLE 6-1:	SPATIAL SCALES, ECOLOGICAL PROCESSES AND ENVIRONMENTAL ISSUES	98
TABLE 7-1:	VARIABLES OBSERVABLE BY REMOTE SENSING AND NEEDED FOR CLIMATE CHANGE MODELLING AND PREDICTION	107
TABLE 9-1:	AVAILABILITY OF KNOWLEDGE AND TECHNOLOGY FOR THE IMPLEMENTATION OF THE ON-LINE NATIONAL POLICY ATLAS (ONPA) FOR SUSTAINABLE DEVELOPMENT	149
TABLE 9-2:	R&D NEEDS FOR THE ONPA IMPLEMENTATION.....	150
TABLE 12-1:	VARIABLES TESTED FOR MODELLING NEW LIGHT DUTY VEHICLE MARKET SHARE	185
TABLE 16-1:	MAGNITUDES OF CONTRIBUTIONS TO SUBCOMPACT MARKET SHARE BY THEMATIC VARIABLES	245
TABLE 16-2:	MAGNITUDES OF CONTRIBUTIONS TO MIDSIZE CAR MARKET SHARE BY THEMATIC VARIABLES	246
TABLE 16-3:	MAGNITUDES OF CONTRIBUTIONS TO LARGE CAR MARKET SHARE BY THEMATIC VARIABLES.....	246
TABLE 16-4:	MAGNITUDES OF CONTRIBUTIONS TO SMALL VAN MARKET SHARE BY THEMATIC VARIABLES.....	247
TABLE 16-5:	MAGNITUDES OF CONTRIBUTIONS TO SMALL UTILITY MARKET SHARE BY THEMATIC VARIABLES.....	247
TABLE 16-6:	COMPARING THIS FORECAST WITH HISTORICAL DATA: MARKET SHARE CHANGES 1991-1993	277
TABLE 16-7:	COMPARING THIS FORECAST WITH J.D. POWER'S FORECAST: MARKET SHARE TRENDS 1996-2001	277
TABLE 16-8:	AVERAGE CANADIAN NEW LIGHT DUTY VEHICLE FUEL INTENSITY	279
TABLE III-1:	PREDICTOR VARIABLES IN THE NEW VEHICLE MARKET SHARE MODELS	292

List of Figures

FIGURE 5-1:	SUSTAINABILITY POLICY PROCESS AND POLICY MAKING	81
FIGURE 5-2:	PROCESS OF CLIMATE CHANGE POLICY MAKING	91
FIGURE 9-1:	A CONTENT FRAMEWORK FOR THE ON-LINE NATIONAL POLICY ATLAS FOR SUSTAINABLE DEVELOPMENT	136
FIGURE 9-2:	POLICY ISSUE MAP MODEL OF THE ON-LINE NATIONAL POLICY ATLAS.....	137
FIGURE 9-3:	THE ON-LINE NATIONAL POLICY ATLAS: A FUNCTIONALITY MODEL	138
FIGURE 9-4:	THE ON-LINE NATIONAL POLICY ATLAS IN BRIDGING THE GAPS BETWEEN THE POLICY COMMUNITY AND THE GEOSPATIAL INFORMATION PRODUCTION AND GEOMATICS TECHNOLOGY	148
FIGURE 10-1:	CANADA'S GREENHOUSE GAS REDUCTION TARGET	160
FIGURE 10-2:	CANADA'S GREENHOUSE GAS PROJECTION BY SECTOR	161
FIGURE 12-1:	THE FRAMEWORK FOR MODELLING AND BUSINESS-AS-USUAL FORECASTING FOR NEW NEW LIGHT DUTY VEHICLE MARKET SHARE, SALES, AND AVERAGE FUEL INTENSITY, AT THE CENSUS DIVISION, PROVINCIAL AND NATIONAL LEVELS	189
FIGURE 14-1:	PRIMARY METHODOLOGY FOR MODELLING AND FORECASTING NEW LIGHT DUTY VEHICLE MARKET SHARE AND SALES	207
FIGURE 14-2:	TWO REGIMES FOR THE CORRELATION BETWEEN POPULATION AGE GROUP 30-44 AND THE MARKET SHARE OF SMALL VANS.....	213
FIGURE 14-3:	SPATIAL REGIMES OF THE CORRELATION BETWEEN NEW LIGHT DUTY VEHICLE FUEL INTENSITY AND SMALL UTILITY TRUCKS	214
FIGURE 14-4:	PROCESS OF FORECASTING NEW LIGHT DUTY VEHICLE SALES MIX.....	225
FIGURE 14-5:	PROCESS OF NEW LIGHT DUTY VEHICLE SALES FORECASTING.....	227

List of Charts

CHART 1: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE (LDV) SLAES - CANADA	241
CHART 2: NEW LDV FUEL INTENSITY FORECAST: CANADA AND SELECTED PROVINCES.....	242
CHART 3: PROJECTED VEHICLE PURCHASE AND FUELING SAVINGS.....	243
CHART 4: PROJECTED VEHICLE PURCHASE SAVINGS.....	244
CHART 5: PROJECTED VEHICLE FUELING SAMINGS	244
CHART 6: PROJECTED PERCENTAGES OF POPULATION AGED FROM 25-44 AND FROM 55-74	245
CHART 7: PROJECTED HOUSEHOLD AVERAGE INCOME.....	245
CHART 8: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SALES – ATLANTIC PROVINCES.....	249
CHART 9: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SALES - QUEBEC.....	249
CHART 10: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - ONTARIO	250
CHART 11: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - MANITOBA.....	251
CHART 12: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - SASKATCHWAN	252
CHART 13: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - ALBERTA	252
CHART 14: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES – BRITISH COLUMBIA	253
CHART 15: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - MONTREAL	274
CHART 16: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - TORONRO	275
CHART 17: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES - VANCOUVER.....	275
CHART 18: FORECAST OF CLASS SHIFT OF NEW LIGHT DUTY VEHICLE SLAES – CANADA (CALIBRATED)	281

List of Maps

MAP 1: MARKET SHARE OF NEW SUBCOMPACT CARS - 1991.....	255
MAP 2: MARKET SHARE OF NEW COMPACT CARS - 1991.....	256
MAP 3: MARKET SHARE OF NEW MIDSIZE CARS - 1991.....	257
MAP 4: MARKET SHARE OF NEW SMALL VANS - 1991.....	258
MAP 5: MARKET SHARE OF SMALL UTILITY TRUCKS - 1991.....	259
MAP 6: FORECAST OF NEW SUBCOMPACT CAR MARKET SHARE - 2010.....	260
MAP 7: FORECAST OF NEW COMPACT CAR MARKET SHARE - 2010.....	261
MAP 8: FORECAST OF NEW MIDSIZE CAR MARKET SHARE - 2010.....	262
MAP 9: FORECAST OF NEW SMALL VAN MARKET SHARE - 2010.....	263
MAP 10: FORECAST OF NEW SMALL UTILITY VEHICLE MARKET SHARE - 2010.....	264
MAP 11: FORECAST OF NEW SUBCOMPACT CAR MARKET SHARE CHANGES – 1991-2010.....	265
MAP 12: FORECAST OF NEW COMPACT CAR MARKET SHARE CHANGES – 1991-2010.....	266
MAP 13: FORECAST OF NEW MIDSIZE CAR MARKET SHARE CHANGES – 1991-2010.....	267
MAP 14: FORECAST OF NEW SMALL VAN MARKET SHARE CHANGES – 1991-2010.....	268
MAP 15: FORECAST OF NEW SMALL UTILITY VEHICLE MARKET SHARE CHANGES – 1991-2010.....	269
MAP 16: AVERAGE NEW LIGHT DUTY VEHICLE FUEL INTENSITY -1991.....	270
MAP 17: FORECAST OF AVERAGE NEW LIGHT DUTY VEHICLE FUEL INTENSITY - 2010.....	271
MAP 18: FORECAST OF AVERAGE NEW LIGHT DUTY VEHICLE FUEL INTENSITY IMPROVEMENT.....	272
MAP 19: POLICY SCENARIO FORECAST OF NEW LIGHT DUTY VEHICLE FUEL INTENSITY FOR 2010: FUEL TAX INCREASE BY \$0.0.5.....	287
MAP 20: POLICY SCENARIO FORECAST OF NEW LIGHT DUTY VEHICLE FUEL INTENSITY FOR 2010: FUEL TAX INCREASE BY \$0.50.....	288

List of Appendices

APPENDIX 1	326
DATA SOURCE DESCRIPTIONS	326
<i>A.1 Data for Modelling</i>	<i>326</i>
<i>A.2 Data for Projection.....</i>	<i>327</i>
APPENDIX 2	328
LIGHT DUTY VEHICLE SIZE CLASSIFICATION (ORNL 1989)	328
APPENDIX 3	330
ESTIMATES OF NEW LDV SALES MIX AND SALES MODELS	330

List of Acronyms

ANOVA – Analysis Of VARIances
CD – Census Division
CEO – Earth Observing System
CGDI – Canadian Geospatial Data Infrastructure
CO₂ – Carbon Dioxide
COPS – Conference of Parties to the United Nations Framework Convention on Climate Change
CIESIN – Centre for International Earth Science Information Network
CNG – Compressed Natural Gas
CSDSS – Collaborative Spatial Decision Support Systems
CSISS – Centre for Spatially Integrated Social Sciences
CVIOC – Canadian Vehicle In Operation Census
DOE – Department of Energy, US
EAE – Efficiency and Alternative Energy Program, Energy Sector, NRCan
ENGO – Environmental Non-Government Organization
FEM – Fuel Economy Model
GCM – Global Circulation Model
GHG – GreenHouse Gas
GCOS – Global Climate Observing System
GOOS – Global Ocean Observing System
GTOS – Global Terrestrial Observing System
GIS – Geographical Information Systems / Geographical Information Science
GC – Government of Canada
GCDIS – Global Change Data and Information System
GEOIDE – Geomatics for Informed Decisions: a major Canadian geomatics research initiative
GNP – Gross National Product
GPS – Global Positioning Systems
HEI – Health Effects Institute
HLB – HLB Decisions Economics Inc., US
IFSD – Inter-Fuel Substitution Model
IGBP – International Geosphere-Biosphere Programme
IMAGE2 – Integrated Model to Assess the Greenhouse Effect, version 2.0
IMF – International Monetary Fund
IPCC – International Panel on Climate Change
JMM – Joint Meeting of Energy and Environment Ministers
LDV – Light Duty Vehicle
LM – Lagrange Multiplier statistic
LR – Likely Ratio statistic
MAUP – Modifiable Areal Unit Problem
MTPE – Mission to Planet Earth
NASA – National Aeronautics and Space Administration
NCAR – National Centre for Atmospheric Research
NCGIA – National Centre for Geographical Information Analysis

NEMS – National Energy Modelling System, US
NRCan – Natural Resources Canada
ODA – Official Development Assistance
OLAM – On-line Analytical Mining
OLAP – On-Line Analytical Processing
OLS – Ordinary Least Square
TEDM – Transportation Energy Demand Model
ONPA – On-line National Policy Atlas
SD – Sustainable Development
SDI – Spatial Data Infrastructure
SOLAP – Spatial On-Line Analytical Processing
UN – United Nations
UNEP – United Nations Environmental Programme
USGCRP – US Global Change Research Programme
VFEIS - Vehicle Fuel Economy Information System
WCB – World Climate Programme
WCED – World Commission on Environment and Development

Chapter 1

Introduction

1.1 Origin of the Topic

The Declaration on Environment and Development, approved at the Earth Summit in Rio de Janeiro in 1992, launched the world into a new era of development – a development that aims to meet the needs of the present without compromising the ability of future generations to meet their needs, so-called sustainable development (UN 1992a, WCED 1987).

Since then, Agenda 21, a comprehensive action plan on sustainable development resulting also from the Earth Summit, has been serving as a guiding principle for government policies across the globe (UN 1992b, UN 1999). International political communities have been engaged in the development of various treaties, to address imperative issues of environmental sustainability, such as climate change and biodiversity. The United Nations Framework Convention for Climate Change and the Kyoto Protocol for greenhouse gas reduction, for example, are the landmarks of the international commitment to stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the earth's climate (UN 1992c, UN 1997a). Participating countries have subsequently embarked on formal processes of policy action formulation to implement the treaties. At the same time, the research community has been continuing inquiry into the complex interrelationships of the earth system, and the improvement of predictions of future changes as bases for international policy decision making (IPCC 1995, IPCC 1997, NASA 1999). The World Climate Programme (WCP 1999), the International Geosphere-Biosphere Programme (IGBP 1999), as well as the US Global Change Research Programme (USGCRP 1999), represent worldwide efforts to advance human knowledge of the earth environment.

The environment has a spatial dimension: natural resources as the source of input to human economy are spatially distributed; most sinks that absorb the waste output from human society have a spatial extent; and the life-support system has a spatial characteristic as well. Likewise, the human community, as part of the earth biotic community, is dispersed across the planet, with locality being an important attribute in its process of development, formation of cultures and interaction with the environment. Geographic space, therefore, constitutes an important dimension of sustainable development issues, and spatial dynamics a significant characteristic of sustainable development policy-making.

Geomatics is a branch of information science and technology that deals particularly with geospatial information. As it has evolved from its original discipline of surveying and mapping, it aims to portray the earth through data acquisition, manipulation, analysis and visualization. With its significant advancements in recent decades, particularly in satellite remote sensing (CIESIN 1999a), Geographical Information Systems (GIS) (Maguire et al. 1991), and the Global Positioning System (GPS) (Dana 1999), geomatics technologies have been widely used in the research of global environmental changes.

Most significantly, remote sensing, complemented with GPS, has been serving as an essential means of earth observation, as evidenced by the variety of large scale environmental monitoring programs, including the Global Climate Observing System (GCOS 1997), Global Ocean Observing System (GOOS 1998), and Global Terrestrial Observing System (GTOS) - the elements of the World Climate Programme and the International Geosphere-Biosphere Programme. In the subsequent phases of data processing, GIS have been playing a crucial role, particularly in the manipulation, integration and visualization of earth observation data, along with a vast range of socio-economic data (Adams/GIS World 1998, Coppock and Clark 1993, Goodchild et al. 1993, Goodchild et al. 1996a). As such, they have been facilitating the integrated consideration of socio-economic and environmental factors in policy decision making – the main principle of sustainable development (Gottsegen 1995, Watson and Wadsworth 1996, Walker and Young 1997). In addition, the development of Internet-based

geomatics technologies, such as Spatial Data Infrastructure (SDI) and Internet mapping, has been improving the accessibility to the geospatial data as well as information¹(CIESIN 1999b, EC 1999, NRCan 1999a, USGCRP 1999b).

The applications of geomatics in the context of sustainable development, however, are found to be limited in three aspects. First, *efforts are very limited*, although observable, *on using GIS in support of strategic policy-making dealing with sustainable development* (Maxwell and Costanza 1994, RIVM 1997, Walker and Young 1997, Wellar and Smith 1992). Second, with the few observable applications in policy-making, the *policy issues involved are confined to those to which the solutions are spatially explicit*, such as land use and ecosystem management (Gottsegen 1995, UNEP/RIVM/PE 1997, Walker and Young 1997). Third, for applications in both environmental research and sustainable development policy-making, GIS are used mainly for data manipulation, integration, management and visualization. From the large body of literature that the author has surveyed, *none is found addressing modelling, forecasting and policy scenario assessment, using GIS and the associated modelling techniques* (e.g. Adams/GIS World 1998, Edwards 1996, Densham et al. 1995, Fisher et al. 1992, Goodchild et al. 1993, Goodchild et al. 1996b, Longley and Batty 1996, Worral 1991).

With the recognition of the limitations of GIS application in global change research, the U.S. NCGIA (National Centre for Geographical Information Analysis) developed a research initiative to address this issue (Goodchild et al. 1996a). Entitled “Multiple roles for GIS in US Global Change Research”, this initiative identified seven broad research areas, including data models, interoperability, spatial analysis, global population databases, global spatial data policy, digital library research and education linkage. To narrow its research agenda, this initiative eventually focuses on the research of data models, the issue believed to be fundamental in GIS application to global change research, particularly environmental modelling (Goodchild et al. 1996a P5). The potential role for GIS for policy-making was not addressed in this initiative. Some

¹ Geospatial data refers to the data with a geographical reference. Likewise, geospatial information refers to the information with a geographical reference.

research activities in relation to this issue are found within other research initiative of the Centre, namely the development of collaborative spatial decision support systems (Densham et al. 1995). But given its technical emphasis, this initiative is not intended to, and did not lead to, a thorough inquiry into this issue either (NCGIA 1999), nor does the other literature that the author has surveyed. Moreover, *there appears to be no effort to thoroughly investigate the potential of GIS, and more broadly, geomatics solutions, in support of sustainable development policy-making.*

It is the recognition of the potential of geomatics to sustainable development policy-making, and the current limitation in the realization of this potential that gave rise to this thesis research.

1.2 Objectives

This thesis will conduct an interdisciplinary study, to advance the role of geomatics in the process of sustainable development policy-making. The following are the research objectives:

- (1) To perform a thorough analysis of the potential roles of geomatics in support of sustainable development policy-making, and to develop conceptually a solution to significantly advancing some of these roles. Specifically:
 - To characterize sustainable development policy-making processes, with climate change to be used as a case, and to elicit, from this process, the general requirements of sustainable development policy-making in relation to geomatics;
 - To examine the current status and opportunities of geomatics in meeting these requirements, and to identify the gaps of geomatics technologies and knowledge for further addressing these requirements;
 - Based on the above analyses, to develop conceptually an integrated solution to substantially advance the roles of geomatics in support of sustainable development policy-making.

- (2) To explore, through a case study, the feasibility of a spatial statistics approach² to the development of predictive models in support of policy scenario assessments aimed at greenhouse gas emission reductions - the seemingly aspatial, currently most imperative policy issue dealing with environmental sustainability. Particularly, the case study will achieve the following objectives:
- To develop spatially-disaggregated new light duty vehicle sales mix models for Canada, at a level that meets the requirements for supporting policy-making aimed at improving average fuel efficiency;
 - To reveal the major determinants of Canada's new light duty vehicle market share, through the modelling process;
 - To perform policy scenario forecasting, on the assumption of no additional policy intervention and fuel tax increase policy intervention respectively, of new light duty vehicle sales mix and average fuel intensity, in order to test, and showcase, the capability of spatially-disaggregated models in support of policy scenario assessments; and
 - To reveal spatial diversity of Canada's new light duty vehicle sales mix and average fuel intensity, and thereby to demonstrate the importance of considering spatial diversity in policy-making, as well as the usefulness of spatially-disaggregated models in support of such policy assessments.
- (3) To perform an analysis of different approaches to sustainable development, and based on this analysis and the advancements in the sustainable development discourse, to briefly articulate a consistent theory and methodology for sustainable development³, in order to lay out a context and provide a guideline for the undertaking of this thesis research.

1.3 Areas of Concern

As an interdisciplinary study, this thesis will involve sustainable development, climate change, policy process and geomatics. Business intelligence technology will be

² The spatial statistics approach refers to the use of spatial regression in combination with geographical information systems for model development. It is also called a spatial approach, a spatial econometric approach and a geomatics approach in this thesis. Refer to Chapters 12 and 14 for details of this approach.

considered, and the areas of energy modelling and vehicle market research in relation to climate change policy will be included.

1.3.1 Sustainable Development

Sustainable development as an emerging approach to development requires the development of theories and methodologies for reconciling the contradictions between the sustainability of the environment and the development of humanity (van den Bergh and van der Straaten 1994a). Interpreted mainly as environmental sustainability, sustainable development will be the substantive area to which the potential of geomatics application is intended to be applied in this thesis. An in-depth study of this area lays out the larger context for the research. It will also enable the elicitation of theories and methodologies as a guideline for the analysis of sustainable development policy-making, as well as for the identification of the potential of geomatics in support of the policy-making process.

As sustainable development involves a wide range of disciplines including ecology, economics, geography, politics and policy, a number of multidisciplinary, or transdisciplinary, studies are emerging which address this issue from different perspectives. Among them are environmental studies with an emphasis on the interactions between society and the environment, environmental economics emphasizing the integration of environmental valuation into economics (Bromley 1995), environmental ethics dealing with human morality with regard to nature (Ferre and Hartel 1994), to list a few. Ecological economics appears to be the most comprehensive area of study, which "seeks to constitute a true marriage of ecology and economics so as to give meaning and substance to the idea of sustainable development" (Jansson et al. 1994, van den Bergh and van der Straaten 1994a). This thesis will draw on the insights from different disciplinary perspectives, with a focal inquiry into the economic systems that are capable of dealing with the contradiction between the environment and development,

³ Sustainable development is interpreted as environmental sustainability in this thesis.

the ethics and political ideology in support of such systems, and the worldview consistent with these ethics and ideology.

1.3.2 Policy Science

With policy loosely defined as a set of interrelated governmental decisions to address particular problems, policy science seeks to characterize and theorize the complex process of public policies and policy-making (Howlett and Ramesh 1995 p3). With the aim of providing a context for the analysis of the potential of geomatics in support of sustainable development policy-making, this thesis will involve the characterization of the policy process dealing with sustainable development issues, particularly climate change. An emphasis will be placed on policy-making – a subset of the policy process.

1.3.3 Climate Change

Climate change, as the most prominent issue of sustainable development, is two-sided. The science of climate change constitutes one side (Trenberth 1992). It attempts to understand the complex relationships existing in the dynamic system of the earth climate, to identify the trends of climate variation as well as the causes for the variation, and to predict climate change on a long time scale. The other side is concerned with societal responses to climate change (UN 1992c, UN 1997a). Represented mainly by policy actions in the political area, it deals with the reduction of greenhouse gases in order to reduce the danger of human-induced climate warming. As climate change will serve as an example of sustainable development issues throughout this thesis, and the policy-making process, as addressed in this thesis, is defined to also include the sub-process of problem identification, this thesis research will involve the two sides. However, they will be discussed in an integrated manner, under the framework of policy process, with an emphasis on the policy side.

1.3.4 Geomatics

Geomatics, a modern technological science dealing with spatial information, is a major area of concern for this thesis. In addressing the first objective of this thesis, all the major areas of geomatics in relation to sustainable development policy-making will be examined, including remote sensing as the principal means of earth observation, geographical information systems for geospatial data handling, the global positioning system for field survey, and the Internet-based geomatics technologies for the dissemination of geospatial data, information and knowledge.

Spatial statistics, particularly spatial regression, and GIS will be the major areas involved in achieving the second objective of the thesis, namely the case study for applying geomatics to modelling, forecasting and policy scenario assessment in support of climate change policy formulation. Closely associated with GIS, spatial statistics represents one of the most recent advancements of statistics that deals specifically with geospatial data (Anselin 1988, Griffith 1988, Haining 1990). While many methods are still under development, an array of techniques is available now for spatially-based linear regression modelling in dealing with spatial effects (c.f. Section 12.2.1) - the distinctive problems of geospatial data that often cause misleading inferences and models in geospatial data analysis and modelling. The application of these techniques, however, remains a challenge, due to the complexity of the issues as well as the solutions.

1.3.5 Energy Modelling and Vehicle Market Research

Another area of concern for this thesis will be energy modelling, the area of study aimed at forecasting energy consumption, assessing policy scenarios and supporting market research (NRCan 1996a, NRCan 1996b). Given the broad penetration of energy in the economy, energy modelling is usually decomposed into sub-areas including industrial, commercial, residential and transportation. Within this framework, the case study in this thesis will address a component of transportation energy modelling, in the context of climate change policy formulation. In particular, it will involve the modelling and

forecasting of new light vehicle market share in relation to energy efficiency – a critical indicator for the development of greenhouse gas reduction policies.

1.3.6 Business Intelligence Technology

The emergence, and rapid evolution, of business intelligence technology in the past decade are aimed at extracting useful information and knowledge from the vast and constantly expanding business databases in support of corporate strategic decision making (Information Discovery 1999). Of particular relevance to this thesis are the recent advancements in Internet-based technologies, including On-Line Data Processing (OLAP), data mining, and knowledge access (c.f. Section 9.2).

1.4 Research Methodologies

Despite its interdisciplinary nature, this research falls primarily in the area of social science. The depth hermeneutics approach (Thompson 1990 p277), a methodological framework for social inquiry, will generally be adopted for this research, with statistical analysis and modelling to be used within this framework.

According to Thompson, the depth-hermeneutical framework comprises three principal procedures, which are analytically distinct dimensions of a complex interpretative process. The first procedure is social-historical analysis, which aims “to construct the social and historical conditions of the production, circulation and reception of symbolic forms”. Formal or discursive analysis is the second procedure, which is “concerned primarily with the internal organization of symbolic forms, with their structural features, patterns and relations”. Methods for this phase of analysis, as Thompson suggests, include semiotic analysis, argumentative analysis, conversation analysis, syntactic analysis, and narrative structure (Thompson 1990 p287). The main methods to be used in this research will be the first two: the semiotic analysis which “focuses on the symbolic forms themselves and seeks to analyze their internal structural features, their constitutive elements and interrelations, and to connect these to the systems and codes of which they are part”; and the argumentative analysis which characterizes the discourse through the

construction of chains of reasoning into patterns of inference, “which lead from one theme or topic to another, in a way that is more or less cogent, more or less implicit”. The third procedure of the depth-hermeneutic approach is interpretation or re-interpretation. Building upon the discursive analysis as well as the social-historical context, this procedure synthesizes and creatively constructs possible meanings.

Generally following this methodological framework, this thesis first contextualizes this research, through an in-depth examination of the theories and methodologies embedded in the pursuit of sustainable development. Within this inquiry, a framework of causes for the environmental crisis is laid out first. The relatively distinctive approaches to environmental sustainability, either proposed or in practice, are then reviewed in terms of their ability to address these causes. Based on this analysis and drawing on recent insights from various disciplines as well as the author’s personal experience and evaluations, an alternative approach to sustainable development is articulated.

The research then addresses the topic of the role of geomatics in support of sustainable development policy-making. First, the processes of sustainable development policies and policy-making are characterized. Connecting these processes with the articulated theory and methodology for sustainable development, and mapping these issues into the spatial dimension, the research then identifies the characteristics and challenges of sustainable development policy-making in relation to space. The current status of geomatics applications in addressing these challenges is examined, followed by an analysis of the gaps and opportunities for geomatics to further address these challenges. With a focus on supporting policy action formulation - the core process of policy-making - an effort is then made to develop an integrated solution conceptually, to bridge the gaps between geomatics and sustainable development policy formulation. Major research topics that need to be addressed in order to implement this solution are further identified.

A case study then follows to address one of these research topics - exploring the feasibility of spatial statistical modelling for the development of predictive models in support of scenario assessments of sustainable development policies. The model

development in support of Canada's national policy-making dealing with climate change, particularly greenhouse gas reductions from new light duty vehicles, is chosen as the case. First, the policy context of the case study is elaborated, followed by an analysis of the rationale for exploring the spatial approach to model building. A conceptual framework of modelling, forecasting and policy scenario assessment is then designed, with a special consideration given to the consistency of this modelling effort within the larger context of Canada's energy modelling (NRCan 1997⁴). Within this conceptual framework, spatial statistics in combination with GIS is used, to explore the factors that determine new LDV sales mix, and to develop spatially-disaggregate, empirical models for new light vehicle market share. A major effort is made to deal effectively with spatial dependence and heterogeneity existing in the geospatial data, through integrated uses of spatial statistics and GIS, in order to obtain more reliable inferences and models.

The research proceeds to demonstrate the use of the spatially-based vehicle sales mix models in support of the formulation of climate change policies, particularly transportation energy efficiency policies. First, a business-as-usual forecast is performed for new light vehicle market share as well as average fuel intensity, at the local, provincial and national levels. A brief analysis interprets the trends and regional differences with regard to new LDV sales mix and average fuel intensity. A policy scenario forecast follows, to test the effectiveness of the policy options of fuel tax increases on average fuel efficiency improvement.

Throughout this research, special attention is paid to the interpretation or re-interpretation of the major symbolic forms concerned. In particular, the meaning of sustainable development is sought through an in-depth analysis of different approaches to environmental sustainability. This analysis puts the current practice of sustainable development policy-making into perspective. In the analysis of causal relationships of vehicle choice and the interpretations of the models, forecast and policy scenarios, special attention is also drawn to the real world situations, in order to avoid the possibility of

⁴ The latest version of Canada's Energy Outlook was produced in November 1999. However, throughout this thesis, comparison is made only to the 1997 Outlook, since data used for this study is consistent to that used in the 1997 Outlook.

being deceived by the imperfect data, as well as modelling methodology. During the process of case study, close communications were maintained with the transportation fuel efficiency policy designers and analysts at the Energy Sector of Natural Resources Canada, who are both the source of policy expertise and the potential users of the case research outcomes.

1.5 Thesis Structure

This thesis consists of three main parts. Part I addresses the larger context of the thesis research, namely the theories and methodologies which inform sustainable development discourse. The framework of causes for the environmental crisis, the existing approaches to environmental sustainability, and the articulation of an alternative approach to sustainable development, each comprises a chapter of Part I, composing Chapters 2 to 4.

Part II addresses the roles of geomatics in supporting sustainable development policy-making. To allow for the analysis of geomatics' roles, Chapter 5 briefly characterizes the process of sustainable development policy-making, with climate change used as a policy case. The major requirements for supporting this process in relation to space or geomatics are elaborated in Chapter 6. Chapter 7 examines the current status of geomatics in meeting these requirements. The challenges and opportunities for geomatics to further address these requirements are identified in Chapter 8. To meet the challenges for supporting national policy action formulation, Chapter 9 proposes an integrated solution, namely the development of an on-line national policy atlas for sustainable development.

The last part presents the case study, a research effort to advance one of the major research topics identified for the implementation of the on-line national policy atlas in particular, and to showcase a link between geomatics and sustainable development policy making in general. Chapter 10 addresses the policy and modelling context of the study. The objectives of the case study are described in Chapter 11. Chapters 12 to 14 address the implementation of the case study, including the conceptual framework used for

modelling and policy scenario forecasting, the definition of variables and processing of data, and the methodology for model building and scenario forecasting. The outcomes of the case study are presented in Chapters 15 to 17, with respect to the models of new light vehicle market share, the forecasting of new light vehicle sales mix and average fuel efficiency, and the forecast of fuel tax increase scenarios.

Each part contains an introduction and conclusions. In addition, the thesis starts with an introductory chapter (this chapter), and ends with overall conclusions and recommendations in Chapter 18 and 19, respectively. Four appendices are provided with the thesis, including descriptions of the data sources used in the case study, the light duty vehicle size classification used in the case study, the estimates of new light duty vehicle sales mix and sales models, and the maps of new light duty vehicle market share and average fuel intensity for major vehicle size classes.

Part I

Environmental Choices for Sustainable Development: Theory and Methodology

Introduction to Part I

Industrial civilization has developed for a mere two centuries, 0.2% of human history, and 0.000002% of earth life. However, it has brought fundamental changes to humanity, nature, and the relationships between humanity and nature. On the one hand, we see the seemingly astounding successes of humanity - space exploration, telecommunication, bioengineering, computer technology, etc. - through which at least one fourth of human inhabitants on earth have been living with wealth, freedom and knowledge. On the other hand, however, we see mounting failures in relation to nature - acidification, soil degradation, desertification, toxic wastes contamination, species extinction, and potentially more threatening, global climate change - all of which have imposed tremendous stress on the life-support system of nature. The extent of the potential impacts has led scientists to suggest that we are conducting what amounts to a global experiment on the biosphere, with potentially fatal consequences for humanity (Robinson et al. 1990). Interwoven with the environmental crisis has been mass poverty in the South, which, partly caused by environmental degradation, has been in turn reinforcing the deterioration of the environment.

The bewildering array of successes and failures has aroused a spectrum of mixed feelings. At one extreme, optimists have faith that technology and the market will resolve any environmental problems. At the other extreme, pessimists believe that "future wars will be those of communal survival, aggravated or, in many cases, caused by environmental scarcity" (Kaplan 1994). Thus, the recent decades have witnessed a series of environmental debates, most noticeably that of the population explosion in the late sixties, the limits to growth in the seventies, and air pollution and global atmospheric change in the eighties. The growing scientific consensus on global environmental

change, its likely nature of irreversibility and its potential impacts on humanity, has eventually brought the issue of environmental sustainability into the international political agenda. The Earth Summit in Rio de Janeiro in 1992 marked a world-wide consensus toward sustainable development (SD), although there were many differences of opinions especially between “developed” and “developing” countries.

The most widely accepted definition of sustainable development is that given by the Brundtland Report (WCED 1987), namely the development that meets the needs of the present without compromising the ability of future generations to meet their needs. While this definition involves considerable ambiguity (Lele 1991, Redcliff 1992), it is commonly understood that an essential issue of this concept is environmental sustainability, namely the need for the existence of the environmental conditions necessary to support human life at a specified level of well-being through future generations (Lele 1991). It is also widely agreed that sustainable development as a principle, aims at integrating environmental objectives into the social and economic process.

With an aim to contextualize this thesis research, Part I is devoted to an inquiry into the theories and methodologies for sustainable development, with environmental sustainability interpreted as the central meaning of SD. The causes of the environmental crisis in relation to social and economic development are first addressed in Chapter 2. Chapter 3 provides an overview of the existing major approaches to sustainable development, each followed with an analysis of their strengths and weaknesses in addressing the causes. Based on the analysis of the weaknesses and drawing on the recent insights from different disciplinary perspectives, an alternative approach to sustainable development is articulated in Chapter 4.

Chapter 2

Causes of the Environmental Crisis

Extensive literature has been devoted to the analysis of the causes of the contemporary environmental crisis (Pearce and Warford 1993). This chapter outlines a causal framework for the environmental problematique, in order to provide a basis for the analysis of theory and methodology of sustainable development. The environmental crisis is broadly ascribed to four main sources: an environmental-detrimental mode of production, over-population, poverty, and resource over consumption.

2.1 Environmentally-detrimental Mode of Production

The environmental-detrimental mode of production contributes directly to the environmental problematique. The main impacts include environmental pollution, over-exploitation, and inefficient resource use. The causes for these negative effects are wide-ranging; among them are environmental externalities, failures in government policies, technology limitations, and relations of production. (Daly and Cobb 1994, Bishop and Woodward 1995).

According to mainstream economic theory, competitive markets in private goods achieve a Pareto Optimality in which no individual can be made better off without making some other individual worse off (Peet 1992 p56). But in reality, everything has some spillover effects, namely "*externalities*", which can be both negative and positive. Environmental effects are one type of externality, which is usually negative and can be differentiated into localized and pervasive (Daly and Cobb p55 1994). Fairness requires that the actors be credited for the positive effect and debited for the negative effect. In the standard economic practice, these are generally realized through a subsidy and a tax.

An environmental tax may deal well with a negative *localized externality*, for instance, a factory whose effluent into a river spoils fishing downstream. This externality could be internalized through an effluent tax, which would give the factory the incentive to reduce

pollution through the use of cleaner technologies and, at the same time, send a signal to the consumers to economize the consumption of this factory's goods. The more challenging and realistic issue of environmental effects is, however, that of *pervasive externalities*, such as the impact of the polluted river on the local ecosystem and, more significantly, the effects of global greenhouse gas build-up. In this case, the areas of pollution are common properties or "free goods", for which the valuation of the pollution is either extremely difficult or impossible. Standard economic theory lacks capability to deal with these issues.

The prevention of pervasive environmental externalities, therefore, is left largely to the *authority of government*. Few governments, however, have exercised adequate authority over the pervasive externalities; the action on the ozone layer depletion caused by the use of chlorofluorocarbons appears to be more an exception than a common practice. The reasons are multifold. First, there is usually a significant delay of the signals of environmental feedback to human activities, due to the limitation of sciences in understanding the functions of the life-support system. Second, there usually exist large uncertainties regarding the effects of environmental changes on human societies. Third, there are considerable pressures from the interest groups who may be affected by government policies. In addition, the reductionist approach, a reflection of the modern mechanistic worldview, has penetrated every institution of government, such that actions involving multiple institutions are extremely difficult to take.

Another factor that directly contributes to the environmental crisis is *technology*. The state of technology and the availability of human-made capital impose constraints on the development of environmental-benign technology. A more fundamental problem with technology, however, lies in the reductionist approach to scientific research and technology innovation. Through this approach, the whole scientific paradigm is reduced to separate disciplines, with the aims of science and technology being reduced to knowledge and innovation. As a result, the environmental issues are almost exclusively ignored in technology development.

In addition, the *relations of production*, in particular the private ownership of means of production in the market economy, is also a factor that tends to make the mode of production detrimental to the environment. Within a competitive economic system, each firm has to minimize cost in order to compete. The intensive competitiveness, both nationally and internationally, generally impels firms to oppose tight environmental regulations and avoid any changes that may entail additional costs.

2.2 Over-population

Human population has been growing exponentially in recent times, especially since World War II (Meadows et al. 1992, p25). According to the United Nation's estimates, world population is likely to reach eight billion by 2050, a doubling of the population in 1975 (Redcliff 1987 p30). The rapid growth of population, combined with the increasing rate of resource consumption per capita, has resulted in a continued expansion of the energy-matter throughput from planetary sources, through the human economy, to the planetary sinks. As Daly and Cobb (1994) point out, the economic system, as a subsystem of a finite, nongrowing, and materially closed ecosystem, has grown relative to the containing ecosystem to the extent that the remaining natural capital (including natural resources and environmental service) has become scarce relative to human-made capital, reversing the previous pattern of scarcity.

For developed countries, population growth rates are low, but the high average rate of consumption per person makes a small rate of growth a significant addition to resource consumption. For less developed countries, such as China, the dramatic increase of population in recent decades, to a large extent, has leveled off the increase of economic output, and imposes tremendous pressure on natural resources as their economies are rapidly growing. For least developed countries, uncontrolled population growth has been interwoven with poverty, causing the collapse of society and pushing the environment beyond its carrying capacity (Kapland 1994, Taylor 1992, Redcliff 1987).

The causes of population growth tend to vary with countries as well. In individualist countries, typically USA, having children is seen as an *individual right*, part of legitimate human rights. Population stabilization is expected to be reached through the *demographic transition* - namely from a period of high birth and death rates, through a period of high birth rates and low death rates, to a new balance of birth and death rates where both are low (Daly and Cobb 1994 p243). The drive to this transition is economic growth. Collectivists have generally been even more pronatalist than the individualists, since producing citizens for the Motherland has long been thought of as a contribution to the *power of the nation*. A view underlying this ideology is a modernist one - the more people, the larger power to conquer nature. Although this conception has been changed in recent decades (especially in China), the *huge population bases* resulting from this conception, together with the incomplete social welfare system, make the control of population growth in these countries an extremely challenging issue. For least developed countries, there are complex reasons for the tragic *population-poverty loop*, concerning external, internal, and environmental factors (see the next chapter for more analyses).

2.3 Poverty

There are more hungry people in the world today than ever before in human history (WCED 1987 p29). The mass poverty, in many places in Africa and South America, has disabled the traditional mode of shifting cultivation. The consequence has been the destruction of forests to create export earnings, as well as poor farmlands that cannot even support those who till them. Tremendous environmental stress thus results, locally leading to increasing flooding, droughts and desertification, and globally causing the loss of carbon sink and impoverishment of biodiversity. The reasons for poverty are especially complex. Taylor (1992 p217) notes,

there is no simple explanation for the current state of affairs, since a complex set of external, internal and environmental factors are involved. These are . . . closely interlinked and no one factor operates in isolation.

Internally, poverty has to do with *systematic injustice, oppression, neglect* from those who are not poor, and “the high level of *governmental and bureaucratic domination* of the economy with its consequences of inefficiency, profligacy and inappropriate control” (Mabogunje 1988, cited by Taylor 1992). The *scarcity* of historically accumulated industrial capital has as well severely limited the process of development. For many African countries, *environmental conditions*, such as drought, excessive rainfall and soil erosion have imposed additional constraints that brought many rural people beyond the edge of survival. Poverty leads to high infant mortality. High infant mortality in turn leads to high birth rate, since families rely on birth to insure their care and security in old age. With high birth rate, any agricultural improvement has been absorbed not in feeding hungry people more but in feeding more hungry people. Consequently, birth becomes both the result of the crisis and the means to cope with the crisis. A *poverty-population positive feedback loop* thus forms, mutually reinforcing (Meadow et al. 1992 p40). The tragic loop has been further worsened by the *lack of training, information, employment opportunity for women, access to birth control, mismanagement*, and in some cases strong institutional objection to abortion.

Interwoven with the internal causes are a series of external factors that contribute to the poverty and environmental crisis. Where agencies like the World Bank have made loans to promote development, the environmental and social consequences have often been disastrous (Redcliff 1987 p57). In order to pay back the *debt*, the borrowing countries have to follow an *export-led developmental strategy*, through the exploitation of natural resources. Decisions over the use to which natural resources are put are influenced by the trading patterns established by developed countries; *terms of trade* are manipulated by developed countries in their favor; and interest rates are kept high. The structural adjustment program introduced by the International Monetary Fund (IMF) has further required the debtors to export more, consume less, and shift away from their sustainable productive basis (Redcliff 1987 p59). Consequently, the poor have become deeply trapped in indebtedness, and increasingly dependent on the rich for their livelihood. The scale of the debt servicing problem has reached such a level that, despite Official

Development Assistance (ODA) flows, there is a net flow of capital from poor to rich countries in many instances (Taylor 1992 p215).

ODA, given by the developed countries to the third world, sounds like a great blessing. However, as Redcliff (1987 p63) comments, the priority “is not given to those who need it most, but to those whom the aid-givers choose for political and strategic reasons, rather than the eradication of poverty.... There is evidence too that cash handouts tend to reach those farmers who are well connected, rather than those in greatest need”. Food aid, in particular, has often created more problems than it has addressed. For example, imported food at low price has reduced the demand for the food locally produced through subsistence agriculture. As a result, with emphasis on specialization and the use of fertilizers, modern agriculture tends to replace the traditional model of cultivation, causing the *break-down of peasants' sustainable livelihood*, the decrease of biodiversity, and the degradation of land.

2.4 Resource Over Consumption

Resource consumption as a means to human welfare is justifiable from both ecological and ethical points of view. The problem lies in resource over consumption or consumerism. It is attributable to the inefficient resource consumption pattern as Western lifestyle, growth as a major developmental strategy, and industrial competitive materialism as a social value.

2.4.1 Inefficient Resource Consumption as Lifestyle

Resource inefficiency can be found everywhere in the Western lifestyle, from energy use to material consumption, and from commercial areas to households. The *pricing* of goods that does not reflect the full cost of their production, resource depletion and environmental *externalities* is one of the primary factors leading to the inefficiency. In addition, the *interest of large resource corporations* in keeping the existing technology and markets makes the substitution of nonrenewable resources for renewable resources very difficult. Any changes in the inefficient resource consumption pattern require a

strong *political will*, which is lacking in many governments. *Technology* limitation, caused by both the level of technology advancement and ignorance of environment and resource depletion, further reduces the level of resource efficiency.

2.4.2 Economic Growth as A Developmental Strategy

Over-consumption is also related to the ideology of economic growth. Quantitative economic growth, normally measured by GNP, has been a major *developmental goal* for governments exclusively. It is often seen as the major area of welfare subject to political influence. The GNP measurements are also used by international financial agencies to measure the comparative success of development programs (Daly and Cobb 1992 p62).

The *trickle-down theory*, which states that the economic gains of the wealthy will spread over to the poor through a trickle-down process, further strengthens the pro-growth stance. While macro economic growth and the market do not imply just distribution, the trickle-down effect is supposed to ensure that everybody will get better off as the economy is growing in a healthy market. Growth is thus a natural and elegant alternative to direct poverty alleviation and income redistribution within a market economy. For a socialist system, growth is equally important in alleviating poverty, since the poor are supposed to be helped by means of redistribution, the capacity of which is enhanced by growth.

Another factor in support of the pro-growth argument is the need for *investment* in research and development, in order to provide substitutes for non-renewable resources and environmentally-benign technologies. Growth is regarded as a major means to enlarge the tax dollar pool, so that the government will have sufficient capacity to stimulate resource substitution and gear consumption toward a pattern in favor of the environment and resource conservation.

While quantitative growth could be achieved through the improvement of resource efficiency to some extent, to date little evidence suggests that an economy has grown without the increase of resource throughput (Pearce and Warford 1992). Thus, as

governments interfere with the market in attempt to stimulate growth, the level of resource consumption corresponds with a persistent tendency of growth.

2.4.3 Industrial Competitive Materialism as Social Value

The more challenging and deeply seated cause of over-consumption, however, is the industrial competitive materialism, which stems from the widely attacked conception of modernism. Modernism is founded on *scientific materialism*, a Western philosophical breakthrough in the seventeenth century made primarily by Bacon, Newton and Descartes. Scientific materialism holds that: the universe consists of materials and minds; the material universe functions like machinery, with mechanistic laws controlling all the processes, and *Homo Sapiens*, as the only species with the mind capable of reason, ought to conquer the material universe through discovery and creativity. By grasping the materialist, mechanistic principle, Hobbes and Locke, the founders of modern political philosophy, analyzed the complex appearance of society into its underlying motions, and established that personal liberty, expressed as *self-interest*, was the proper basis for activities of people in a society (Peet 1992 p168). Natural laws called each individual to ceaselessly strive for more material acquisitions and power, in order to realize not only basic material needs, but competitive high social values such as social recognition, honor and vanity (Kassiola 1992 p125).

Taking Hobbes and Locke's ideas further in formulating a theory of economics to reflect the universal truths of economic behavior, Adam Smith further suggested that *the market* - the interaction of atomistic individuals in a freely operating exchange of goods and services - was the natural expression of material self-interest. So long as each individual was as free as possible, the "invisible hand" would ensure that socioeconomic activities would be as efficient as possible and society would be as perfect as possible (Peet 1992 p169). The pursuit of individual self-interest would ensure the health and well-being of society as a whole.

Thus, *individualism* became the basis of modernist political philosophy, being institutionalized in the economic system through the market. As a result, human nature

and social life are reduced to the desire for material goods both for what they need and what they are. Kassiola (1990 p141) cites an interpretation of Marx's analysis of capitalism (a social system with the market as its primary form of economy):

Relations among people in capitalist production assume the form of relations among commodities. The resulting commodity fetishism reinforces consumerism, for it emphasizes the importance of material goods - rather than social relations - as the primary source of individual welfare.

In short, the environmental problem is not only one of economic activity, technology and government policy, but also one of distribution, relations of production, political economy and political ideology. More fundamentally, it is rooted in the modernist morality in respect to human, nature, and the relationship between human and nature.

Chapter 3

A Brief Review of Major Approaches to Environmental Sustainability

The analysis of the causes of the environmental crisis indicates the vastness and depth of the environmental problematique. Sustainable development aimed at dealing with the environmental problems thus poses challenges not only for human economic activities, but, more fundamentally, for the modernist conception of human, nature, and the relationship between human and nature. The entire social system constructed on the modernist conception, including ethics, politics, economics, institutions, science and technology, production and consumption - indeed the entire industrial civilization - is brought into question. Any approaches to sustainable development therefore must adequately address these questions.

Although intellectual inquiry into such approaches can be dated back to a century earlier when John Stuart Mill and others were concerned about ecological sustainability, current thinking about this subject has its roots in the 1960s and 1970s, when the exponential growth of human population and the sudden increase of energy price were causing alarm. Four approaches articulated or in practice since then are found to be relatively distinct, namely the cornucopian, mainstream, social ecology, and deep ecology approaches. Table 3-1 outlines these approaches in terms of objective, economic system, technology, developmental strategy, power distribution, political ideology, ethics and worldview.

3.1 Cornucopian

Cornucopians, also called interventionists, place a profound faith in the limitless capacity of human beings and the unlimited substitutability of resources. They believe that, while some resources may become scarce, as long as there exists free market, human ingenuity stimulated by market competition will always enable their substitutions, be they human made, human or natural resources. As Simon and Kahn (1984) state (cited by Peet 1992 and O'Riordan 1989):

The nature of the physical world permits continued improvement in humankind's economic lot in the long run, indefinitely. . . The ultimate constraint upon our capacity to enjoy unlimited raw materials at acceptable prices is knowledge. . . Of course, there are always newly arising local problems [but] the resilience in a well-functioning economic and social system enables us to overcome such problems, and the solutions usually leave us better off than if the problem had never arisen.

Likewise, cornucopians believe that pollution can be ameliorated by technological changes that spontaneously make production cleaner as economies grow. There is no need either to worry about population growth, for more people means more problem solvers. Sustainability is thus not a problem; the only obstacle to human's rosy future is misguided government intervention (Dryzek and Lester 1995).

Table 3-1: Major Approaches to Environmental Sustainability

Approach	Cornucopian	Mainstream	Social ecology	Deep ecology
Objective of SD	As usual	Sustaining capital	Leaving natural capital intact	Minimum resource use
Economic system	Market	Market & increased government interference	Market subordinate to social goals; strong government control	Informal market
Technology	Advanced technology	Advanced technology	Appropriate technology	Appropriate technology
Developmental strategy	Quantitative economic growth	Economic growth with emphasis on quality	Limits to economic growth	Simple material life
Power distribution	Decentralized to Market	Centralized	Decentralized + centralized	Decentralized to community
Political ideology	Individualism	Individualism	Person-in-community	Communitarianism
Ethics	Anthropocentric	Anthropocentric	Ecocentric ethical view point, anthropocentric focus in approach	Ecocentric in both view point and approach
Worldview	Materialistic, reductionist	Between materialistic & organistic	Organistic, holistic	Organistic, holistic

(Compiled by the author from a variety of sources)

Ethically and philosophically, the cornucopian approach is rooted in modernism. Nature is conceived as merely resources for human manipulation and consumption. Humans with mind and rationality are superior to nature, capable of discovering and conquering

nature. Indeed, it is only human's intervention with nature that makes nature invaluable. In other words, nature has instrumental values, which are realized only when used by humans.

Obviously, this approach is not intended to address any of the causes of the environmental crisis. It is essentially not an approach to sustainable development, rather it is typically a modernist one, the approach that has brought about all the environmental problematique in the first place. O'Riordan points out in 1989, however,

interventionists still essentially control the levers of political and economic power in all countries, totalitarian, socialist, or capitalist. Those responsible for governing tend to have a deep faith in the ability of humanly devised systems to conquer adversity. . . . Interventionists may be a numerical minority but, in terms of effective influence, they remain very powerful.

Theoretically, the territory of this approach should have been shrinking since then, thanks to the increasing scientific evidence on the environmental crisis, and the growing global consensus on sustainable development. In reality, however, the cornucopian conception has been built into human hearts for centuries, and will not easily go away.

3.2 Mainstream Approach

The mainstream approach to sustainable development came to prominence in the Brundtland Report (WCED 1987), although it can be traced back to the first World Conservation Strategy in 1980, and to the United Nations Conference on Human and Environment in 1972. The Report points out that the world cannot support the continued growth of current economic practices. It calls for the reviving of economic growth with emphasis on *quality* and *equity*. Although the second World Conservation Strategy excludes the pro-growth position and calls for a reduction of resource consumption in the Western countries, the Rio Declaration and the much larger text of Agenda 21, resulting from the Rio Earth Summit in 1992 as an international consensus toward sustainable development, mainly reflects the principles of the Brundtland Report.

3.2.1 A Brief Overview

For mainstream thinkers, sustainable development is necessary for the following reasons. First, environment degradation has been affecting millions of people in the Third World; the interlinked nature of most environmental problems is such that environmental degradation will ultimately affect everybody. Second, we have no right to exploit the natural endowment of future generations, but the current pattern of resource consumption is likely to leave future generations with an impoverished world in terms of both resource depletion and environmental pollution. Third, present generations of every nation have the right to develop: for the poor, it is to provide basic needs and increase the productivity of all resources; and for the rich it aims to maintain and improve the standard of living. Thus, what is required is a unified approach to both the environment and the development, the present and the future. Sustainable development aimed at meeting the needs of the present while preserving the ability to meet the needs of the future provides such an approach (WCED 1987, Lele 1991, Redcliff 1992, O'Riordan 1989, Pearce 1993).

The mainstream approach to sustainable development is therefore anthropocentric. It acknowledges the interconnections between human beings and nature. But nature is conceived as resources for, and constraints on, human development. Sustainable development as a goal of humanity is interpreted as a continued increase in - or at least maintenance of - human welfare over time, while overcoming the environmental constraints (Pearce and Warford 1993 p49). From this aim are derived several main principles: sustaining capital stocks, reviving economic growth while improving resource efficiency, eradicating poverty and managing population growth. The operationalization of the former two principles, to a large extent, depends on environmental economics, a modification of neo-classical economics which originated in the late 50's and flourished during the past two decades. Information is therefore of particular importance to the mainstream approach.

Sustaining Capital Stocks

Sustaining capital stocks addresses the future focus of sustainable development. It is derived from mainstream economics. In particular, the welfare interpretation of sustainable development is consistent with the idea of a Pareto improvement for society as a whole, where society is taken to embrace current and future generations. But the Pareto criterion, as stated earlier, has limited applicability to sustainable development, since most policies for sustainability would make some people worse off and some better off. This criterion is therefore modified into the principle of hypothetical compensation, which states that a policy increases social welfare if the losses caused by the policy are outweighed, and can be compensated, by the gains brought about by the policy (Pearce and Warford 1993 p49). Under this principle, however, a policy that produces gains in the present but losses in the future can be justified if the current gains could be used to compensate future generations. What is further required is therefore to preclude the current generation from engaging in policies that actually make the future generation worse off. A solution to this is to require intergenerational compensation (Pearce and Warford 1993 p51). Sustaining capital stocks is regarded as a preferred form of intergenerational compensation.

Sustaining capital stocks suggests the conservation of the overall capital stocks. But capital can be differentiated into two types - human-made capital and natural capital. The mainstream approach therefore implies that substitution can take place between natural and human-made capital. It also suggests that the extent of this substitution depends on the comparative rate of social return. Depleting natural capital should be allowed only if the proceeds from doing so are invested to secure a higher rate of return in human-made capital.

However, there are some natural capital stocks, such as the life-support functions, that are critical for humankind and their substitution is difficult or even impossible. The safe minimum standards approach has therefore been proposed to deal with such special capital stocks (Randall and Farmer 1995, Pearce and Warford 1993 p56). Its basic rule is

that natural capital stock should only be destroyed if the benefits of doing so are very large.

A crucial issue to capital substitution is thus the valuation of natural capital. For the natural capital that provides conventional goods and services, markets provide important information about values. For natural capital that allows for free access, a pseudo market price can be derived from the value of the marketed product, based on the resource via the production function. For environmental amenities, for which markets do not exist, the dominant approach is that of willingness-to-pay or -accept, i.e., households or individuals are asked about the values they place on changes in the quality and quantity of directly consumed environmental commodities; the other choice is to try to capitalize on links between environmental quality and market goods (Balmey and Common 1994, Bishop and Woodward 1995).

With natural capital being valued, the principle of sustaining capital stocks can then be operationalized through such techniques as cost-benefit analysis and environmental impact assessment. In mainstream sustainable development practices, the latter has essentially been the most important means in support of decisions for the substitution between human-made and natural capital.

Reviving Economic Growth while Improving Resource Efficiency

For mainstream thinking, sustainable development implies not merely the conservation of capital stock, but also the increase of aggregate human welfare. Given that economic growth is understood as an important component of welfare, the mainstream approach therefore promotes the reviving of economic growth, with an emphasis on the quality and equity of growth. It is also assumed that economic growth is consistent with environmental goals: for the South, growth is a necessary means to development and poverty alleviation; for the North, growth will strengthen the capacity to invest in resource substitution and environmentally-benign technology, and at the same time to provide finance and markets for economic growth in the South.

The contradiction between growth and its environmental impacts, according to mainstream thinking, can be reconciled through the improvement of resource efficiency. In particular, any economic activity must always affect the environment, since some natural resources have to be consumed and some wastes have to be produced. But the amount of resource consumed and the amount of waste produced per unit of economic activity can be reduced, namely the quality of growth can be improved. If the reduction proceeds at a faster rate than the rate of economic growth, then the total amount of resource consumption and waste disposed of can be reduced over time (Pearce 1995 p115, Pearce and Warford 1993 p15). The general recommendations with regard to resource consumption are thus as follows: renewable resources should be consumed at the rate not exceeding the rate of their replenishment; non-renewable resources should be conserved through the improvement of their efficiency in the short term, and their substitutions should be sought in the long term; the impacts of resource consumption on the life-support system should be reduced by improving efficiency, changing patterns of consumption, and adopting clean technology.

To this end, it is suggested that environmental concerns be integrated into social and economic policy decision-making. Johnson (1995 p12), based on a detailed analysis of the green plan countries (the Netherlands, New Zealand, and Canada) in dealing with the environmental issues, emphasizes the critical importance of a comprehensive, integrated and large scale commitment for the success of sustainable development initiatives.

Politically, the mainstream approach suggests that "extension, elaboration, and refinement of existing social and political traditions and attitudes" (Dryzek and Lester 1995 cited from Cahn 1978) would best serve the purpose. Minor structural reforms, such as increasing the capacity of the department of environment, establishing cross-departmental committees, and setting up an Environmental Auditor in Parliament, are thus widely adopted (with the exception of New Zealand). An increasing involvement of business and environmental groups in the process of decision making is particularly promoted for more coordinated and coherent policies (Johnson 1995 p136). Johnson also points to several features that are of considerable importance for the cause of

environmental sustainability, namely visionary leadership, a strong political constituency, a consensus around environmental goals, public awareness of the environmental program for both the big picture and individual responsibilities, and the appropriate roles of environmentalists. Goals, timelines, monitoring and reporting are of great importance as well for the success of environmental endeavors (Johnson 1995 p133).

In terms of economics, environmental economics has devoted great efforts to revising the system of national accounting, in attempts to reflect environmental costs and natural resource depletion using economic indicators. Methods proposed include the Hicksian income, the El Serafy's non-renewable resource receipt method, and the index of sustainable economic welfare (Daly and Cobb 1994, p69). Attempts have also been made to incorporate environmental externalities into cost benefit analysis, based on the valuation techniques discussed earlier (Johansson 1993). Full cost pricing is suggested to capture the full value of both natural resources and commodities (Pearce and Warford 1993 p59). The price for natural resources should include the costs of extraction, environmental costs and user costs, where user costs refer to the future benefit that is lost because of unsustainable management. The price of commodities should encompass the environmental externalities caused during their production, according to the polluter-pay principle.

Policywise, the mainstream approach favors economic instruments, with the assistance of command and control tools. Among others, direct environmental taxes are introduced to represent environmental costs; tradable pollution permits and resource quotas are also suggested, despite some controversy; levies and fiscal incentives, such as feebates (Davis et al. 1993), are applied to environmentally harmful and benign consumptions respectively; and subsidies detrimental to the environment are abolished (Johnson 1995 p126, Pearce 1995 p118). These instruments are attempted to send the correct signals to producers and consumers, thereby gearing production and consumption towards resource conservation and environmentally-benign patterns. Also, the issue of assigning property rights to free resources is debated in seeking solutions to protect the commons. At the consumer end, recycling, reduction and reusing are widely promoted to improve material

efficiency and reduce wastes. It is believed that "by creating a broader mix of instruments, including market incentives, thereby avoiding constraints on the technologies used to achieve higher standards, environment policy can stimulate investment, innovation and competitiveness rather than stifle them" (Johnson 1995 p118).

Internationally, the mainstream approach has been seeking international agreements for protecting global commons and the improvement of trade policies in relation to the environment. A variety of international agreements have been formulated to date, most noticeably, Montreal Protocol, the Framework Convention on Climate Change and the Convention on Biodiversity. Mere agreements, however, are inadequate given the huge difference between the South and North. To ensure global cooperation, it is acknowledged that resource transfers from North to South are required. This is because the global sinks of human waste output are common to all nations, but the North has appropriated a much larger portion of the global commons than it should in the process of modernization, leaving little room for the South which has yet to develop. Moreover, even with the political will to conserve the global commons, the South is unable to do so financially. Also, the North has been responsible for past uncompensated exploitation of biological resources (Pearce 1995 p159). The North to South resource transfers are therefore justified. Currently, the transfers proceed tentatively through the Global Environmental Facility (Pearce 1995). The resources most critical for transfer are resource efficient and environmentally-benign technologies.

An issue under extensive debate regarding the approach to enable economic growth in developing countries is the extent of free trade (Pearce 1995 p74). Generally, mainstream thinkers believe that freer trade outweighs its costs, since protection causes production and consumption losses and encourages "rent-seeking" and "direct unproductive profit" seeking. Consequently, economic growth is impeded. The question is therefore how to remove the side effects of free trade on the environment, rather than eliminate free trade itself. The General Agreement on Tariff and Trade (GATT) is recognized to have ignored the environmental effects to a large degree. More emphasis is therefore placed on the environmental issue by the World Trade Organization (WTO)

than its preceding form, GATT. At the same time, the mainstream thinkers suggest that environmental impacts should be controlled by well-targeted environmental policies in the country of export (Pearce 1995 p100).

Population and Poverty

The link between population, poverty and resource degradation in the South is widely recognized in the mainstream thinking of sustainable development. Elements in this link are mutually reinforcing. The greater the population, the higher the pressure on natural resources, leading to the lower chance to meet human needs (poverty). In turn, poverty, along with limited health care and other social defects, leads to high infant mortality, hence a high birth rate for family survival. It also causes resources to be overexploited, especially when intertwined with indebtedness. The mainstream approach also acknowledges the importance of intragenerational equity and income redistribution for poverty alleviation (WCED 1987 p50, Johnson 1995 p22), but sophisticated theorizing and practical proposals on these issues are rarely seen in the sustainable development discourse.

The solutions suggested to poverty and over-population, thus, have been mainly techno-economic ones, including designing for efficiency; proper resource pricing, managing common resources, attending to basics, building management capability, promoting family planning, and increasing employment opportunities for women (Lele 1991, who cited from Repetto 1986). Strong measures for population control are denied, since having children is considered as a human right. While self-sufficiency and community development have been widely discussed and practiced, structural adjustment aimed at paying international debts is still emphasized by the World Bank, a major international agency promoting sustainable development. Also, it is believed that freer trade would provide the best means to eradicate poverty, but resource-intensive exports are not only unsustainable, but also unfair to the poor in terms of the equality of resource appropriation. Calls are therefore made for the reduction of protectionism by the North (WCED 1987 p79) in order to allow the South to diversify their exports.

Information and Computer Modelling

The key prerequisite for the operationalization of the mainstream principles of sustainable development is information. A wide range of information is involved, including the characteristics of the life support system and stocks of natural resources; the levels of stresses on the environment and the sources of stress; the changes in the environment and their effects on human and ecosystem health; and the effects of human responses to environmental changes as well as their impacts (Kumar et al. 1993 p66). Such information allows for the identification of environmental problems and their causes. It also provides a basis for the design of environmental policies and the monitoring of their impacts.

However, mere information, for the mainstream approach, is inadequate for environmental policy decision support. A variety of computer models are indispensable as well. In particular, models are required for the anticipation of environmental degradation and natural resource depletion. They are as well a necessary tool for cost-benefit analysis and policy scenario exploration.

To meet informational needs, the mainstream approach identifies four areas in which immediate action is required: (1) broadening and deepening the base of scientific and technical knowledge concerning the fundamental links between the economy and the environment; (2) extending and improving monitoring systems, and increasing the cost-effectiveness of information management technologies; (3) widening the accessibility and sharpening the "decision relevance" of environmental reporting; and (4) strengthening and expanding partnerships among institutions that currently produce, analyze, and disseminate environmental information (Kumar et al. 1993 p68).

3.2.2 Strengths and Weakness

Although differences of opinions still exist, especially from the cornucopians who have large political influence, the mainstream approach appears to have gained support from a wide range of actors. As Lele comments (1991), "from profit-minded industrialist and risk-minimizing subsistence farmer to equity-seeking social worker, the pollution-

concerned or wildlife-loving First Worlder, the growth-maximizing policymaker, the goal-oriented bureaucrat, and therefore, the vote-counting politician", everybody seems to be united under the flag of sustainable development. The main strength of this approach to environmental sustainability thus lies in its wide acceptance and the potential for quick implementation.

In terms of the causal framework of the environmental crisis, the mainstream approach mainly addresses the problems of production and inefficient resource consumption. Its emphasis on reviving economic growth while improving resource efficiency makes it an attractive approach to dealing with resource over consumption. Given the current Western lifestyle, there is indeed a large potential for the implementation of this approach, through appropriate government policies and programs, improved cooperation between governments and industries, and enhanced environmental education for citizens. For example, recycling and reuse could largely reduce wastes and improve material efficiency. Energy consumption as well as emissions could be greatly reduced through the adoption of more energy efficient and clean technologies. Substitutions of oil and gas with such energy sources as windmill and solar energy may lead to breakthroughs in energy sources.

The mainstream approach, however, is inadequate in terms of its capacity to turn societies onto a sustainable development path. First, it is obviously weak in dealing with the poverty and population issues, as well as the general environmental issues in developing countries. The poverty-population-environment link is incompletely conceptualized by the mainstream approach (Lele 1991). Such political issues as the need for deeper social political changes, the impacts of international political economy on the third world, the unjust sharing of global resources between the North and the South (one fifth of the world's population consumes four fifths of natural resources (Johnson 1992)), are either ignored or paid lip-service. Given their intellectual poverty, the solutions prescribed, such as resource transfers and the adoption of clean technology in developing countries, lack a solid ground for implementation. Also, the mainstream approach is based mainly on the developed and least developed countries. While sharing

similar problems, the countries in the process of rapid industrialization are faced with different priorities. Intellectual exploration and practical solutions to these particular problems and contradictions are of critical importance, given their huge population and the tremendous potential of development. The mainstream approach, however, seems particularly poor in this regard. Thus, as poverty lasts or even develops, population grows, and developing countries rapidly expand their economies, the consequence of this weakness is far from minor; it might be fatal!

Second, the mainstream approach is inadequate in addressing the problem of resource over consumption in developed countries. While both the principles of improving resource efficiency and sustaining capital stocks are aimed at resource conservation and environmental pollution reduction, the emphasis of this approach on economic growth, and its faith in the substitution between natural and human made capital, make this approach questionable. Firstly, with the reviving of economic growth being a principle of sustainable development and without a clear objective for reduction of resource consumption, it is questionable whether the improvement of resource efficiency could lead to the reduction of resource consumption. Secondly, the principle of substitution between natural and human made capital essentially encourages the consumption of natural resources. It is also non-precautionary, notwithstanding the Minimum Standard Rule. After all, human understanding of nature is very limited. It is very likely that we could not clearly identify a problem before the problem becomes irreversible; ozone depletion is a typical example.

In addition, environmental economics, despite its attractiveness in theory and methodology, has great difficulties in dealing with real world problems. Be it the modification of national accounting systems, the improvement of cost-benefit analysis, or the incorporation of environmental externalities into natural resources and commodity pricing, the fundamental issue is the valuation of goods for which either the present or the future market does not exist. For the present, the contingency valuation method is based on weak foundations. As Sagoff (1988, cited by King and Slesser 1994) contends, individuals comprise two choosing entities, consumer and citizen, and the consumer

entity is of limited relevance to social choices affecting natural assets. For the future, discounting is the only means to account for the time dimension. The difficulty with discounting is that essentially social decisions are made by one individual, or generation of individuals, whose choices as consumers aggregate through the market at a given point in time - the decisions are therefore extremely hard to make (Gowdy and Olsen 1994, Daly and Cobb 1994 p151).

Most fundamentally, the mainstream approach hardly touches the root of the contemporary environmental crisis - the modernist conception that drives people to the non-constrained preference for more children in the already over-crowded countries, to pursuing self-interest individually, nationally and internationally, and to unlimited material wants as a symbol of self-realization. In particular, it does not touch individualism - the basis of ethics and political ideology of Western societies. Consequently, population control is extremely difficult because reproduction is seen as an unalienable, individual human right. There is no effective solution to poverty alleviation either, because self-interest is legitimate for both individuals and nations. The reduction of resource consumption would be questionable as well, since individuals are still striving for material acquisition under the value system of industrial competitive materialism. Such competition, stimulated further by government policies aimed at economic growth, is very likely to outweigh the efforts for resource efficiency and substitution, thus leading to the increasingly shrinking resource pools for the developing and undeveloped nations. Furthermore, self-interest makes resource transfers to the South remarkably complicated and difficult. Thus, as development proceeds in the global community, both intragenerational and intergenerational equities remain a most significant challenge, as does the sustainability of the earth biotic community. As Adams (1995) suggests, despite its radical promise, the mainstream approach is at the best a short term solution to environmental problems.

3.3 Social Ecology

The inadequacy of the mainstream approach to sustainable development is being criticized by several streams of thoughts. The main thoughts that emphasize the interrelated social, political and economic context of the environmental crisis are termed social ecology. Among them, most noticeably, are political ecology, communalism and ecofeminism.

3.3.1 A Brief Overview

A political ecology analysis offered a powerful Marxist-influenced analysis of social-environmental issues when it first appeared in the 1970s and early 1980s (Rye 1996). In the recent debate on sustainable development, in particular regarding the environmental crisis in the third world, this approach focuses on the complex, open and dynamic nature of social-environment interrelations, avoiding economic, technocratic or naturalistic reductionism, and attempting to theorize the power relations involved (Redcliff 1987). It addresses: (1) contextual sources of environmental change, including state policies, interstate relations and global capitalism; (2) location-specific conflict over access to environmental resources; and (3) the political ramifications of environmental change (Rye 1996).

Increasingly challenged and shaped in the last decade by wide-ranging postmodernist approaches, political ecology also stresses the fundamental importance of epistemology in the debate over sustainable development. Redcliff (1992) points out that the assumption underlying the sustainable development discourse is that the system of acquiring knowledge in the North, through the application of scientific principles, is regarded as a universal epistemology. He draws attention to the distinction made by the philosopher Feyerabend between two different traditions of thoughts, namely abstract tradition and historical tradition. The former corresponds closely to scientific epistemology, and the latter to traditional knowledge, the knowledge encoded in rituals, religious observations, and the cultural practices of everyday life. Political ecology

argues for the crucial role of traditional knowledge in the practice of environmental sustainability, especially in small scale rural societies.

According to political ecologists, the environmental crisis stems from the unequal socio-political systems and structures - the relations of productions. As Bookchin (1971, cited by Dryzek and Lester 1995) argues,

Capitalism is inherently antiecological. Competition and accumulation constitute its very law of life, a law which Marx pungently summarized in the phrase 'production for the sale of production'. . . In a society of this kind, nature is necessarily treated as a mere resource to be plundered and exploited. The destruction of the natural world. . . follows inexorably from the very logic of capitalist production.

Kassiola (1990) further reveals that the social value as well as political philosophy underpinning, and reinforced by, capitalism is industrial competitive materialism - the ceaseless, competitive striving for unlimited materials. The infiniteness of the material desire was regarded by Thomas Hobbes as human nature, which, legitimated through Adam Smith's economic theory, became the basis of capitalism. Capitalism thus became the necessary mechanism through which human beings pursued their unlimited material wants. The desires to accumulate material wealth and advance oneself socially and economically through acquisitive behavior, in turn, became the dominant force driving the wheels of capitalism. The consequences are twofold: the competition for materials results in frustration, dissatisfaction, and fearfulness simply because it is the means to social status based on *comparison*; and such competition inevitably causes the careless exploitation of natural capital, hence today's environmental crisis. Kassiola, therefore, contends that there are not only biophysical limits, but also social limits, to economic growth.

The need for change in these social values is widely recognized in the thoughts of social ecology (Dryzek and Lester 1995, Kassiola 1990, Meadows et al. 1992, Schumacher 1973, Daly and Cobb 1994). The recommended values include the political values of freedom, equality and democracy, and the social values of loving, friendship,

cooperation, self-fulfilling, perfection, aesthetics, caring for the environment, and meaningfulness of life. Kassiola (1990 p181) suggests that a society with such values would be predominantly nonmaterial, normatively enhancing, socially improving and noncompetitive as well as ecologically sustainable.

The recognition of the fundamental problems of capitalism in relation to the environmental crisis has lead social ecologists to seek new ways of civilization. The intellectual tradition of socialism is appreciated in regard to its social principles compatible with most of the values being advocated. Socialism, as the practice of Marxist-Leninism, however, is dismissed for two main reasons. First, economic planning as the primary system of the economy is inefficient. Second, the so-called collective benefits are often realized at a high individual price, including freedom and other basic human rights. In addition, economic growth is as well a primary goal of all socialist countries. What has been sought, therefore, is an alternative to both capitalism and socialism.

Communalism is the main result of this searching. It extends from the anarchist traditions of the last century (O'Riordan 1989). Its modern champion is Fritz Schumacher (1973), the original source for a variety of movements usually termed the new economics. Schumacher points out that modern economics engages in the maximization of consumption by the optimal pattern of productive effort. It disregards the moral importance of work to humans. It makes people and resources "footloose", causing unjust resource exploitation for a luxury lifestyle by the rich and over-exploitation of nature for livelihood by the poor. It also tends to absorb the whole of ethics and to take precedence over all other human considerations. Therefore, unhappiness, inequality, as well as environmental degradation result from modern economics.

An alternative to modern economics, Schumacher suggests, is Buddhist economics. In particular, he argued for "technology with a human face" and production by the masses rather than mass production (Schumacher 1973 p50). He believed that such a mode of

production would offer more jobs to people, be more environmentally-benign and less resource intensive. The relation of production, he suggested, should not merely concentrate on productivity, which makes labour "soul-destroying, meaningless, mechanical, monotonous, and moronic", nor merely on socialist principles, which leads to "a chaotic kind of inefficiency". An alternative he recommended is common ownership shared by employees. He also argued that men organized in small units could take better care of their resources than anonymous companies, and that community on a small scale could better serve its people than a large one.

Bookchin, in a similar vein, envisions a classless, stateless, and decentralized society - the ideal of socialists and anarchists (Dryzek and Lester 1995). But he has no faith in the Marxist-Leninist program of vanguard revolution, seeking instead a spontaneous nonhierarchical transformation from the bottom up. His new society would feature small communities, humanistic technologies, unrepressed sexuality, communal solidarity, individual development, self-discipline, the elimination of toil, and the promotion of craftsmanship. "Thus would be accomplished the reconsideration of nature and human society in a new ecological sensibility and a new ecological society - a reharmonization of nature and humanity through a rehumanization of human with human" (Bookchin 1982 cited by Dryzek and Lester 1995).

Daly and Cobb's recent work, *For the Common Good* (1989, 1994), makes a remarkable advancement to the communalist approach. Based on a thorough and in-depth analysis of economics, they contend that modern economics is seriously flawed in the fact that the theory, like any other theories, is established based on abstraction, but this abstraction is ignored by economists. "One of the most important is the abstraction of a circular flow of national product and income regulated by a perfectly competitive market. This is conceived as a mechanical analog, with motive force provided by individualistic maximization of utility and profit, in abstraction from social community and biophysical interdependence." (Daly and Cobb 1995 p37). Modern economists, however, tend to prize abstraction over fact and reinterpret fact to fit abstraction. Even worse, economics is regarded as the most important theme of government; "instead of economy being

embedded in social relations, social relations are embedded in the economic system". The market is left to handle not only resource allocation, which the market is good at, but the scale of economy and the distribution of economic output, which is beyond the capacity of the market. Consequently, as the economy grows, resultant human and biophysical externalities excluded from the abstraction grow as well. These externalities have now become a vital issue so that we must restructure the basic concepts of economics.

The key concept that needs to be structured into economics, they believe, is community. Economics as a discipline should change from its modern form of chrematistics aimed at profit maximization, to oikonomia characterized by the long-run view, the consideration of costs and benefits to the whole community, and the focus on concrete use value and the limited accumulation thereof (Daly and Cobb 1994 p139). The scale and distribution of the economy should be determined by the government, letting the market solve allocation problems based on these data. Homo economicus as person-in-community, rather than the individualistic Homo economicus as abstracted by modern economics, should be the basis of economic thinking. Economics on this basis should call not only for provision of goods and services to individuals, but also for an economic order that supports the pattern of personal relationships that make up the community.

A community, in their vision, is characterized by relative self-sufficiency, strong community identity and social relationships, radical democracy, responsibility for its members, and respect for individuality (Daly and Cobb 1994 p172). A community could come with all sizes and levels, with decisions to be decentralized to as low level of communities as possible. Self-sufficiency should at least be maintained at the national level. Global free trade and capital flow are opposed since they believe that, unless there is a global government, such policies will benefit global corporations, at the price of reducing average wages in the developed countries.

To this end, they prescribed a series of policies, such as a birth license for restricting reproduction, a negative income tax for redistribution, and political caps on resource

extraction. University reform is recommended, with an aim to direct research towards finding solutions to the challenge of sustainability. A bottom-up approach is suggested to community building, with emphasis on promoting self-sufficiency and close resource-waste flows. Call is also made to change people's attitude to nature.

Ecofeminism shares the political ecologists' antipathy to hierarchy, but is more specific as to the location of this root of all evils. Warren (1994) points out that patriarchy in human society, or hierarchy based on gender, makes other dominations, including the domination of nature, possible (Warren 1994). Ecofeminists, therefore, aim to overthrow all types of dominance. Harcourt (1994), from an epistemological perspective, argues that development theory and practice, founded on the Western hierarchies and assumptions, excludes both women and nature from its understanding of development and, in so doing, has contributed to the current economic and ecological crisis.

In general, social ecologists share the view that the scale of economy must be reduced (Daly & Cobb 1994, Schumacher 1973, Kassiola 1990, Lele 1991). In so far as scale refers to materials and energy throughput, they share this view with the mainstream. But they diverge markedly in believing that these materials and energy scale changes can only be brought about by changes in the scale of GNP, i.e. in economic growth (Pearce 1993 p20). In terms of capital sustainability, they generally espouse that human-made capital and natural capital are more complementary than substitutable. Environmental sustainability, therefore, should aim to keep each of the capitals intact.

Notwithstanding the focus on human issues in relation to the environment, social ecologists generally support ecocentric environmental ethics, acknowledging that the environment is valuable not only for its usefulness for human beings, but also in its own right, including its instrumental values in maintaining the ecosystem, and the intrinsic value of each of its components (Daly and Cobb 1994 p201, O'Riordan 1989). To social ecologists, Leopold's land ethic (see Sections 4.1 and 4.2 for details), as defended by J. Baird Callicott, is more acceptable over other environmental ethics being proposed, including animal rights (Singer 1995 and Regan 1995), the extension of animal rights to

including non-living natural entity (Taylor 1995), and deep ecology's view (Naess 1995, Devall and Sessions 1995).

3.3.2 Strength and Weakness

Social ecologists provide in-depth examinations of the causes of the environmental crisis from social, political and economic perspectives. Their critiques of modern economics and the social values of Western societies are particularly insightful. The recognition that the environmental crisis is rooted in the conception of modernism makes them rethink the theories underpinning the process of industrial civilization, in particular individualism and modern economics. Although they represent a minorstream thinking in the sustainable development discourse, the tide of opinion is shifting from the mainstream to the minor stream. "The gap between the two positions is by no means as large as it was" (O'Riordan 1989). Indeed, Daly and Cobb's work has made a most noticeable contribution to closing this gap. While there is still a long way to go, the apparently increasing interest in this approach does offer some hope that human rationality and ingenuity may eventually give rise to theories and methodologies that are more likely to lead humanity to a sustainable future.

In particular, the concept of communalism as currently articulated offers some promise for dealing with two of the most difficult issues of sustainability, namely resource over consumption and poverty alleviation. First, local self-sufficiency, as regarded as the major characteristic of communalism, would lead to the reduction of the scale of markets as well as production, hence to a lower level of productivity. This could imply that: (1) material consumption be reduced; (2) the capacity of technology innovation be reduced, hence the reduced commodity diversity which reinforces the reduction of material consumption; (3) material competition may be slowed down because of reduced financial resources for business competition. Second, communalism appears to be a promising approach for people's survival. In the poor countries, particularly in rural areas, community-based development does offer a better chance for people to take care of each other, and to ensure that development benefits the poor rather than the elite class (Taylor 1992, Stohr and Taylor 1981, Redcliff 1987). In addition, self-sufficiency also implies

that a community would mainly rely on its local natural resources for its economy, therefore it would tighten the tie between human beings and nature. Reduced population mobility in a communalist framework could also give rise to closer social relationships, and likely to a better social and economic order as well; a community as such could therefore be more capable of taking care of all people. As well, people's wide participation in community decision making is more likely to take place in a small community than in a large urban centre.

The advantages of communalism, however, seem to be accompanied with no less disadvantages. First, reduced productivity would lead to lower level of income as well as lower level of government revenue. This could have multiple implications: (1) people's standard of living would be lowered; (2) the reduction in the diversity of commodities, for many, would mean the lowering of the excitement of material life; (3) technology innovations aimed at resource substitution and environmental protection would also be slowed down; and (4) the level of social welfare would likely be lowered as well. Second, low population mobility would generally lead to less opportunities for career choice, hence less opportunities for self-fulfillment. Third, class structure could become more explicit and fixed in a society where the market comprises the primary form of the economic system, but where people have fewer opportunities to compete in the market. Fourth, as Daly and Cobb (1994 p174) note themselves, the will to gain power within and between communities, the will to sacrifice for one's community, and other characteristics of human beings abstracted from the model of person-in-community, could lead to complicated power structure within communities, strengthen the tension between communities, and thus increase the danger of war. Fifth, the class structure, interwoven with the power structure, is very likely to erode the conditions for equal participation of community decision making. In addition, inevitably accompanied with the close and deep social relationships of a community would be watchfulness, the characteristic that becomes stronger as a community gets smaller. Watchfulness would intensify the individual's tendency for competitiveness, as well as frustrations including those resulting from competition. It would also very likely lead to the formation of community "traditions", thereby restricting human freedom.

It then seems to follow that communalism, for the North, could lead to the reduction of material consumption, tightened ties between humans and between humans and nature, but at the prices of a less exciting material life, lowered levels of social welfare, reduced capacity for resource substitution, reduced opportunities for self-fulfillment, more explicit and fixed class structure, more complicated power relations, strengthened tension between communities, and less human freedom. Moreover, it is difficult to imagine how to put such a theory into practice.

The drawbacks, of course, could become less obvious if a community is sufficiently large, say a nation (termed communities of communities by Daly and Cobb). However, many advantages such as social relationships and the potential for participatory democracy might be reduced at this scale. The sense this community theory really makes, would then seem to be the reduction of resource flows between nations. This would imply less resource exploitation from the South, and the reduction of other economic interactions between nations, including trading, capital flows and aid. Developing countries would therefore rely more on their own capacity to develop. If time were turned back to two centuries ago, this might indeed be a good idea. The problem, however, is that, for the South, the priorities for poverty alleviation and industrialization over sustainability would likely lead to the repeat of the Western's process of development, which could add a tremendous amount of greenhouse gases, most likely resulting from the use of coal, into the atmosphere. The effect could intertwine with many other effects, known or unknown, and lead to fatal damage to the life-support system (Dalby 1997). The limited understanding of the life-support system, or uncertainty, could again be the excuse of inaction until the damage became irreversible.

A classless and stateless society envisioned by Bookchin is more utopian than a solution. As long as the market exists, there will be classes. The elimination of the market, which is the necessary condition to eliminating classes, would very likely cause material supply to fall short, due to the foreseeable lowering of productivity (see Section 4.4 for more

details). In other words, material sufficiency tends to coexist with the market, as well as with the class structure.

In short, the strength of social ecology lies mainly in its thorough and in-depth critique of modernism in relation to the environmental crisis. Its proposed solutions are radical socially, politically, as well as economically. They do offer some promise with regard to achieving environmental and some social goals, but they also bring about perhaps as many additional problems as they intend to solve. Much intellectual as well as methodological exploration is needed, before they could become a practical approach to sustainable development.

3.4 Deep Ecology

The most radical approach to environmental sustainability is that of deep ecology. It refers to the views of a particular school of theorists - Arne Naess, George Sessions, Bill Devall, Warwick Fox, and others - who have articulated a broad ontological, ethical, political, and economic visions pertaining to ecology. The term Deep Ecology was first coined by Arne Naess (1994a) to describe the movement calling for a deeper questioning and a deeper set of answers to our environmental concerns. Naess (1994b) further develops the philosophical implications of Deep Ecology, which he calls "Ecosophy". He calls his version of ecosophy "Ecosophy T", to emphasize that there could be different ecosophies for the movement. This ecosophy, however, seems to have become a basis for the formulation of deep ecology, although the theory as well as the movement is still open to input (Devall and Sessions 1995). In essence, deep ecology is a loose agglomeration of Eastern spiritualism including Taoism, Buddhism and Hinduism, the minority tradition in Western philosophy identified by Aldous Huxley, the worldview of American Indians, and scientific ecology (Dryzek and Lester 1995, Du 1994, Dwivedi 1995, Silva 1995).

3.4.1 A Brief Overview

Deep ecology is biocentric, not only in its position on the relationship between humanity and nature, but also in the issues the theory addresses. In contrast to the "shallow approach" to environmental problems (the mainstream approach), deep ecology questions human life and society that would be best for maintaining the biotic community. It poses a sharp critique of anthropocentric traditions of ethics, "views of the good life that are bound up with high-consumption life styles, and notions of progress that stress industrial expansion and an ever-growing GNP" (French 1995). Based on the critiques, it attempts to articulate a comprehensive religious and philosophical worldview. The foundations of deep ecology are the basic intuitions and experience of human beings and nature which comprise ecological consciousness.

From the most basic insight or characteristic of deep ecological consciousness, Naess developed two ultimate norms or intuitions, which are themselves not derivable from other principles or intuitions, namely Self-realization and biocentric equality (Naess 1995b, Devall and Sessions 1995).

The norm of self realization is the realization of "self-in-Self" where "Self" stands for organic wholeness. More specifically, Self-realization goes beyond the modern Western self which is defined as an isolated ego striving for hedonistic gratification. "Spiritual growth, or unfolding, begins when we ceases to understand or see ourselves as isolated and narrow competing egos and begin to identify with other humans from our family and friends to, eventually, our species" (Devall and Sessions 1995). Realization of self-in-Self is achieved through a further maturity and growth, an identification which goes beyond humanity to include the nonhuman world.

The intuition of biocentric equality, as Devall and Sessions (1995) summarize, is that all things in the biosphere have an equal right to live and blossom and to reach their own individual forms of unfolding and self-realization within the larger Self-realization. They continue:

There are no boundaries and everything is interrelated. But insofar as we perceive things as individual organisms or entities, the insight draws us to respect all human and nonhuman individuals in their own rights as parts of the whole without feeling the need to set up hierarchies of species with humans at the top.

In dealing with the conflict of interest between humans and non-humans, Naess (1995b) holds that biospherical egalitarianism is a principle, and that realistically in concrete practice "some killing, exploitation, and suppression" of non-human life forms must occur. However, he insists, humans have no right to reduce the richness and diversity of life forms except to satisfy vital needs. Practically, it thus implies that human beings should live with minimum rather than maximum impacts on other species and on the earth in general. In other words, "simple in means, rich in ends" (Naess 1995a). The overwhelming propaganda and advertising in Western societies, according to deep ecologists, encourage false needs and destructive desires, which divert humans from the realization of Self. Therefore, the two norms are essentially closely related.

Based on these norms, Sessions and Naess articulated eight principles of deep ecology: (1) the well-being and flourishing of human and non-human life on earth have value in themselves (namely intrinsic or inherent value); (2) the richness and diversity of life forms contribute to the realization of these values and are also values in themselves; (3) humans have no right to reduce this richness and diversity except to satisfy vital needs; (4) the flourishing of human life and culture is compatible with a substantial decrease in human population; (5) present human interference with the non-human world is excessive, and the situation is rapidly worsening; (6) current policies that affect basic economic, technological and ideological structures must therefore be changed; (7) the ideological change is mainly that of appreciating life quality rather than adhering to an increasingly higher standard of living; and (8) those who subscribe to the foregoing points have an obligation directly or indirectly to try to implement the necessary changes. Politically, deep ecology calls for decentralized, non-hierarchical, fully democratic social structures.

3.4.2 Strength and Weakness

Deep ecologists have put forth many important insights that deserve broad attention, particularly their potent critiques of consumerism and population expansion, and their emphasis on the need for a radical identification with nature, and a spiritual revolution aimed at transforming human societies into a sustainable path.

Identification with nature is essentially an extension of human ethics into nature. This extension is justified given the intuition that all living beings have the tendency to proceed with a process of realizing themselves, and the fact that humans are but one species within the biotic community. In essence, identification is a way of personal development that transcends both egoism, which lays the basis for capitalism, and altruism, which has been found to be questionable in socialist practice. It also points to a way in which human competitiveness could be redirected away from material acquisition. It could transform the modernist morality into one that enables a society to be truly in harmony with nature.

In fact, the principle of identification with nature is one of the major characteristics of the ancient Chinese naturalistic philosophy Taoism. Taoism deeply influenced, and is still influencing but to some extent, Chinese societies, particularly intellectuals, for thousands of years. It searches for what it conceives as an elusive mystery, namely the fundamental unity of the world as a whole, and pursues the transcendence of one's narrow self through the identification with the wholeness. It is evident that great satisfaction and enjoyment can be attained through this process of searching and identification.

Deep ecology as an approach to sustainability, however, is far from complete. Dryzek and Lester (1995) comment that it does not have a fully articulated political-economic program. While it intends to question deeper, the movement is not clearly revolutionary, or even clearly political. Some of its adherents advocate and practice a retreat from politics into actions and feelings toward nature.

The norm of biocentric equality raises many questions as well. First, if all forms of life have an equal right to reach their own forms of unfolding and self-realization within the larger Self-realization, why should humans restrict their potential of living into meeting vital needs and identification with nature? The answer may be that human civilization has already caused tremendous damage to the earth community, or to the process of Self-realization. Then, the norm seems non-equal for all forms of life in their process of self-realization; instead, humans with rationality and ingenuity should confine their activities to some extent, so that the health of the biotic community could be sustainable. As Waston (1995) argues, the equality norm, as presently articulated by deep ecologists, seems easily to lead to the interpretation of anti-humans rather than biocentrism. Second, even if the principle of biocentric equality as proposed by deep ecologists is valid, as French points out, the transformation of the equality principle, under the pressure of necessity, into a "realistic egalitarianism", which permits the killing or injuring of animals and plants to protect vital human interests, seems to "take these decisions out of the sphere of morality altogether and turns them into assertions of raw power". Third, for nonhuman forms of life, their values to the health of the biotic community vary. For example, it can hardly be valid to assert that any virus has the same value as pandas and Arctic bears. The norm of biocentric equality cannot explain why we should protect endangered species over other animals or plants.

Moreover, to restrict humans to meet only their vital interests seems to suggest a return to a primitive life. History, however, seems to have shown that it is much easier for humans to seek the path of material growth than that of spiritual identification with other human beings or with nature. Even though the ideal is appealing, its practicality and feasibility, in the age of postmodernity, is very questionable.

In short, deep ecology is more an ideal than a practical approach to environmental sustainability. Although it has absorbed the essence of many non-dominant philosophical traditions, a thorough and in-depth analysis of the ideas in the context of the postmodern age is necessary in order to make them an applicable alternative to the cause of sustainability. To this end, it would also be of great value to examine the reasons why

these traditions were gradually dissolved in favor of the dominant philosophical traditions.

Chapter 4

Towards An Integration of Reductionist and Holistic Approaches

The review of the major approaches to environmental sustainability suggests that none of them are both adequate and feasible for achieving the goal of sustainability. The challenge lies in dealing with the issues that the mainstream approach does not adequately address, and that the approaches of social and deep ecology attempt to address but have yet to provide a realistic solution. In particular, the issues are consumerism, over-population, and poverty.

As analyzed earlier, consumerism is driven by industrial competitive materialism and the ideology of economic growth. Population growth is defended by the individual human right. The efforts to alleviating poverty are jeopardized by the international economic relations based on self-interest. The real challenges, therefore, all stem from modernism. A theory, as a guide toward sustainability, thus needs to address a set of issues embedded in modernism, including a worldview that describes nature, humans and the relationship between them, ethics and political ideology that set up general rules for human conduct, socio-economic systems that make up the social and economic orders of a society, and institutional structures that implement all these concepts. In addition, modern science needs to be examined, given its critical role in Western civilization.

These issues have been addressed by many scholars from different disciplinary perspectives, including, most noticeably, environmental ethics, ecological economics, environmental politics and policies. This Chapter, based on the major approaches to environmental sustainability and the recent insights provided from these disciplinary perspectives, attempts to articulate a brief, but relatively coherent, argument with regard to the key issues involved in the discourse of environmental sustainability. The central argument is that an alternative characterized by a coherent integration of the reductionist and holistic approaches presents the most promising choice. Reductionism is the essence of modernism, while a holistic approach (Du 1994, Merchant 1980) is the quintessence of

Eastern civilization. An integration of these contrasting approaches in addressing the major issues of sustainability may give rise to a way that makes both development and sustainability more possible.

4.1 From Materialism to Organism - A Holistic Worldview

Nature, in the view of scientific materialism, is merely a material realm which can be reduced to atomic particles. Each atom can be described mathematically, and all nature's parts composed of such atoms are thought to be automata following Newtonian laws. Humans are different from nature in that, in addition to a body which consists of materials, they alone have a conscious, rational soul that inhabits the pure mechanistic body. This consciousness and rationality enables them to discover and thereby make use of nature. To discover means to observe and then to conceptualize. Nature thus became the object to be observed, and humans the subject to observe. The human/nature, or subject/object, dichotomy has therefore risen. This radical bifurcation of human and nature is indeed a hallmark of modernism (Callicott 1994). Nature is therefore seen as a raw material, valuable only as a pool of commodities for human use. Humans are the conquerors and nature the conquered. This human-nature relation can further be traced back in the Christian tradition, according to which God created nature as a life-support system for rational man. The idea that humans are superior to nature and thus discontinuous with nature has therefore enjoyed a nearly three-thousand-year tenure in Western intellectual history.

This conception, however, has been questioned since the late 19th century. The first significant breakthrough in this inquiry was Darwin's great works, the *Origin of Species*, and the *Descent of Man*. He elaborately argued that there was a seamless continuity between gradually evolved man and our fellow voyagers in the odyssey of evolution (Callicott 1994). In other words, we are one sort of living, feeling being among many others. Therefore, we are a part of nature, not set apart from it.

Einstein's relativity theory, developed at the end of the 19th century, served as an assault on the Newtonian paradigm. The classic mechanistic laws are shown to be valid only under certain circumstances. Quantum theory, a more recent breakthrough in physics, on the other hand, casts critical doubt on dualism. Callicott (1985) explains that, according to this theory, "to make an observation energy must be exchanged between the object of observation and the observer. That energy is, among other things, information and information energy physicalizes knowledge and consciousness. . . The subject thus collapses into the object". Therefore, "nature is a unity, a whole, and the self, the "I", is not only continuous with it, but constituted by it. Nature and I are conceptually as well as metaphysically integrated."

The development of contemporary ecological science in recent decades has further lead to the establishment of the postmodernist conception of nature. Two main features characterize this conception: everything is related to everything else - the first law of ecology; and nature is inherently dynamic - it is constantly changing and ultimately evolving. More specifically, as Leopold (1995) describes, nature (or land as Leopold calls it) is a complex composite, where plants absorb energy from the sun, and the energy flows through the circuit of biota which may be represented by a pyramid of layers. The bottom layer in this pyramid is the soil, a plant layer rests on the soil, an insect layer on the plants, a bird and rodent layer on the insects, and so on up through various animal groups to the apex layer, which consists of the larger carnivores. The lines of dependency are called food chains, and the pyramid is a tangle of chains which is complex but highly organized structure. Its functioning depends on the cooperation and competition of its diverse parts. Evolution has added layer after layer and the trend of evolution is to elaborate and diversify the biota. Nature thus is "more organistic than mechanistic; organisms proper are integrated wholes with systemic integrity" (Callicott 1995).

The extension of quantum theory across the physical universe has also led to the speculation that "the universe is not a dead thing, composed of separate parts in mechanical interactions; rather, it is organic - an almost living thing in which each aspect subsists on some underlying activity" (cited by Fabel 1994). Fabel notes that the

formative quality rises with and specifies itself through the series of life forms in a complementary dialectic to emerge as self-reflective consciousness, while the underlying activity is the sequential and scalar development due to a comprehensive principle of self-organization. In its evolution to the human phase, it breaks through into self-reflection and reason. "Thus, we see an essential image of an oriented cosmic gestation, as well as an evolutionary paradigm". Fabel continues: various theories, including complex system behavior, discontinuous change, chaos and order, self-organization, nonlinear system behavior, and evolving systems, now converge in an attempt to explore this scientific evolutionary paradigm. The most sophisticated work in this area is found at the Santa Fe Institute and the University of Pennsylvania. The researchers have shown that complex nonlinear systems, such as gnomonic networks, spontaneously arrange themselves in states of dynamic order. This self-organization takes place prior to and in tandem with natural selection. Synthesizing the theories of mind and cognition with the characteristics of self-organizing systems leads further to the belief that "both life and mind are manifestations of the same set of systemic properties, a set of processes that represent the dynamics of self-organization" (Fabel 1994).

The "Gaia Hypothesis" developed by James Lovelock appears to be a simplified vision of this worldview. Stimulated by the Apollo 8 photograph of the earth, Lovelock postulates, and further attempted to confirm, that the planet and its inhabitants constitute a single organic, living entity, capable of manipulating the earth's atmosphere to suit its overall needs and endowed with faculties and powers far beyond those of its constituent parts (Lovelock and Epton 1995).

This organistic worldview, in essence, is a cyclic expression of pantheism, including many eastern traditions and "native minds", but on a basis of a sophisticated scientific paradigm. Taoism, for example, believes that Tian (heaven) or Tao is present in all things in this world including humans. It is a continuous process of creation, and human beings are co-creators within the realm of nature. Nature and human are in a mutually nourishing and harmonious relationship (Du 1994).

All these developments in human understanding of the world have given rise to the emergence of a holistic worldview, which sees Nature as a biotic community and a organic whole, in which humans are a part, and in which all the entities are interrelated and dynamically changing.

4.2 From Individualism to Individual-in-Community - The Emerging Ethics, Values and Political Ideology

This holistic, organistic worldview has three important implications: (1) human beings, like all other living, feeling beings, are but one species of the ecosystem community; (2) the health of the ecosystem is critical to the sustainability of all living species within this complex web; and (3) inappropriate human activities could damage the organism of the ecosystem of which human understanding is very limited, and thereby potentially threaten the welfare of both human and nature, the present and the future. Sustainable development as the highest principle of humanity, therefore, is essentially a declaration of human commitment to restricting human activities in order to ensure nature's sustainability. These implications, along with this commitment, lead to a new set of ethics dealing with nature and humanity.

In particular, the first implication suggests that all living things, like humans, are intrinsically valuable. Proponents of biocentrism thus argue that all living beings own equal rights for realizing their potentials. The basis for this ethical claim is intuition for deep ecologists (Naess 1995, Devall and Sessions 1995), human as a "plain member and citizen" of the biotic community for ecocentrists (Leopold 1995, Callicott 1995), and each individual as a "teleological center of life" for those, such as Paul Taylor (1995), who have provided the strongest defense for biocentric egalitarianism. However, all these accounts, as in the case for deep ecology, are in trouble when dealing with the conflicts between humans and other life forms. Indeed, humans have to invade other living beings for their survival. The aim of these biocentric claims is essentially an ethics dealing with other members of the biotic community in the process of human survival, namely respect for life or, broadly, respect for nature. But in essence, our respect for

nature does not have to be based on the principle of biocentric egalitarianism. It follows directly from our acknowledgment of the inherent worth of nature as well as of its living beings. As diZerega (1995) argues in a moving way:

We, and all other beings, are fellow travelers on the voyage of life. . .A rich, varied, and beautiful world offering a maximum diversity of ways of life to all its inhabitants requires that each of us sooner or later becomes sustenance for others. At this deepest level of insight, there is no top of the food chain. Thus, while it is legitimate for us to make use of other beings to serve our ends, it is equally illegitimate for us to take only instrumental value into consideration when we consider their worth. We owe all beings our respect.

Thus, the Western individualistic ethics that requires respect only for other human individuals needs extension. We should respect not only those of the same species, but also all of those who together constitute the complex earth biotic community. The role of Homo Sapiens should be changed "from conqueror of the land-community to plain members and citizen of it" (Leopold 1995).

The acknowledgment of humans as a plain member of the biotic community may lead to the interpretation that, like the activities of all other living beings, human actions are but part of natural behavior. Humans therefore have no reason to worry about the consequences. The second implication of the organistic worldview, however, makes this interpretation invalid. The organistic nature of the world calls for an ecocentric ethics with regard to the relationships between human and nature. An ecocentric ethics firstly implies the existence of intrinsic values of the earth ecosystem. This is justified by the fact that the ecosystem has certain properties pertaining only to the system (e.g. some thresholds across which drastic change may take place), and that the preservation of these ecosystem properties is invaluable in its own right. Secondly, an ecocentric ethics holds that the health of the ecosystem is the central benchmark measuring the appropriateness of the activities of all living beings (Callicott 1994). While some human activities still have to take place even though they are known to be harmful to the health of the ecosystem, ecocentrism as an ethical principle encourages humanity to find alternatives towards environmental benign behaviors. The norm of Self-realization proposed by deep

ecology is of particular relevance in this context, namely individuals can only realize their potential within the realization of the large Self - the ecosystem. Thus, it is again necessary to extend the individualistic ethics to one emphasizing individuals in relation to the larger ecosystem community.

The third implication of the organicist worldview suggests that our present activities affect not only the biotic community surrounding us, but also other people who share the natural environment with us, and future generations who will inherit the natural environment from us. Our decisions therefore must take into consideration the issues of intergenerational and intragenerational equity. Our concern for intergenerational equity is justified by several facts. First and most fundamentally, humans have a sentiment, a feeling unique to *Homo Sapiens*, that our descendants should enjoy at least as much the material happiness as we do. Second, we as parents normally share an inherent love of our children and wish that they will have a better life than we do; we can thus infer that our children will share this feeling too, so will our children's children, and so on. The concern for future generations reinforces the concern for present justice. As Daly and Cobb (1994, p39) contend,

Families endure only by merging and mixing their identities through sexual reproduction, and thus are not independent or well defined over intergenerational time. . . The farther in the future is the hypothetical descendant, the greater the number of co-progenitors in the present generation, and consequently the more in the nature of a public good is any provision made for the distant future. To the extent that you are concerned about the welfare of your descendant, you should also be concerned about the welfare of all those in the present generation from whom, for good or ill, your descendant will inherit.

Furthermore, the wholeness of organic nature is likely to lead to the fact that developed countries and the rich pollute more but developing countries and the poor are at more risk (Bryant 1995a). This is because developed countries and the rich usually have the far larger capacity to cope with the environmental crisis than developing countries and the poor do. Bryant (1995b) cites Boggs' shocking statistics that "during his/her lifetime an American child cause 35 times the environmental damage of an Indian child and 280 times that of a Haitian child". Many Western people seek pure luxurious goods merely to

indicate defeat of the other competitors while hundreds of millions of other human beings search in vain for adequate food and other requirements for survival. Such a pattern of distribution is certainly unjust. In fact, even regardless of this distributional fairness, all the inhabitants in the earth biotic community would eventually be at risk if developing countries have to repeat the process of development, as well as pollution, of the Western societies (Kaplan 1994, Buttel 1995). Therefore, we need to address the issues of intergenerational and intragenerational equity; and in doing so, we need an ethics that positions individuals in a community, a large and, to some extent, virtual community that encompasses all people, the rich and the poor, the developed and the developing, and the present and the future.

Thus, the holistic worldview and human pursuit of sustainability entail modification of individualism, the outcome of reductionism in the realm of society which has served as the foundation of the modernist ethics and political philosophy. This foundation needs to be extended into one that also reflects the holistic conception of human in relation to the world, namely individual-in-community. While retaining the individualistic ethics of respect for individual rights, the ethics of individual-in-community emphasizes: (1) concerns for all members of the human community extended to the future; (2) concerns for the biotic community of which humans are a part; and (3) concerns for all non-human beings of the biotic community.

As such, the human rights defined under individualism need revision. The revision of the right of reproduction is among the most imperative. As individuals we value reproductive freedom, but as individual-in-community we recognize that such freedom can have unacceptable social consequences. Daly and Cobb (1994, p326) draw attention to John Stuart Mill's classic defense of individual freedom in *On Liberty*, even in which a limitation on reproductive freedom is urged:

The fact itself, of causing the existence of a human being, is one of the most responsible actions in the range of human life. . . And in a country either over-peopled or threatened with being so, to produce children, beyond a very small

number, with the effect of reducing the reward of labor by their competition, is a serious offense against all who live by the remuneration of their labor.

The ethics of individual-in-community also undermines industrial competitive materialism as a social value. In contrast to valuing the competitiveness in material acquisition, the new ethics appreciates the values of material thrift and spiritual growth. The criteria for social recognition shall thus be non-material ones, such as individual's contribution to communities; talents in art, craft and sport; perfection and self-cultivation in literature, philosophy, and aesthetics. Identification with nature, as suggested by deep ecologists, could be one aspect of self-cultivation. Although selfishness is part of human nature, psychological research shows that loving and caring are human characteristics as well. The recognition of individual-in-community urges the promotion of these human characteristics. It also entails such social values as cooperation, solidarity, democracy, respect for nature, responsibility for communities - both the human and the biotic, in addition to respect for other human individuals. Competitiveness as a nature of human beings placed within such a value system is more likely to contribute to the improvement of real human welfare, the alleviation of poverty, and the conservation of the whole biotic community.

As the philosophical foundation of sustainable development, the holistic worldview, and the ideology of individual-in-community (including ethics, values and political philosophy), must be well understood and accepted by citizens. Public campaign, community activity, information package are among the channels that could be used for the moral education. More importantly, these philosophical and moral principles should be included in school curriculums in a systemic manner. Indeed, it is the coming generations with a holistic worldview and the ethics and values based on individual-in-community, that will provide the real hope for turning human development into a sustainable path.

4.3 From Chermatistics to Oikonomia - A Quest for An Economic System

The extension of the ethical foundation and political philosophy from individualism into individual-in-community entails a corresponding change in economic systems. The central issue is the search for an economic system that would be consistent with the emerging ideology of individual-in-community. Ideology is part of what Marx termed the superstructure of a society⁵. According to Marx's analysis of the major contradictions of society, a nation state cannot run well unless its superstructure be compatible with its economic foundation, which includes both the capacity of production and the relation of production.

Capitalism consists of private ownership of the means of production, with the market being the major actor for resource allocation and output distribution. Individual maximization of profit by firms, and of satisfaction by consumers, provide the motive force. By making use of fragmentary market knowledge of individuals while reducing complex social life primarily to the pursuit of individual self-interest, capitalism is proved to be superior in its efficiency in resource allocation and the development of production capacity. Its capacity of production, therefore, is supportive to the ideology of individual-in-community. However, its relations of production leads to the pursuit of self-interest, which is contradictory to this ideology.

Socialism, in general, is defined by the state ownership of means of production, with allocation and distribution controlled by government, namely through central planning. The motive force comes from a combination of moral and material incentives. Its merits include wealth distribution and the pursuit of collective wills. In establishing the individual-in-community ideology, socialism is theoretically more capable of achieving the objective. In reality, however, central planning has been proved to be inefficient in resource allocation, and as a result socialism suffers the serious problem of low

⁵Superstructure includes the series of state mechanisms such as political power, army, and state-owned banks, and all the areas dealing with ideology such as literature, philosophy, history, aesthetics, arts, and social values.

productivity, and therefore lacks the production capacity to meet people's material needs. Thus, while its relation of production are consistent with the individual-in-community ideology, its capacity of production is not, since, as proved in socialist practice, one can hardly pursue high level social goals if individual's material needs are not met. Maslow's theory of human's hierarchical desires tells the truth.

An interesting question then arises: would socialism be suitable for the developed countries where people's material needs are already met? In particular, if Marx's projection that the development of capitalism will eventually lead to socialism is true, then would it be time for this transformation to take place? The answer is that this is questionable. In fact, the two elements of economic foundation - capacity of production and relation of production - are interrelated. Institutionally, it is primarily private ownership that has led to the high capacity of production in developed countries. This capacity of production, however, is by no means static; rather, it is maintained and developed by the dynamic process of resource allocation. A change in the relations of production is very likely to cause the lowering of efficiency, therefore the lowering of production capacity. Moreover, socialism suffers two more problems which further make it not a favorable choice. First, a central planning system restricts individual career choice and, therefore, limits individual creativity and aspiration. Second, collectivism as the political philosophy of socialism likely leads to the ignoring of individual rights, as often seen in socialist practice.

Thus, both capitalism and socialism, as currently defined and practiced, are not consistent with the ideology of individual-in-community. The communitarianism envisioned by Daly and Cobb (1995) and Schumacher (1973), as discussed earlier, suffers serious problems as well. There is therefore *no simple answer to the question of an appropriate economic system*. What we can really find would be some *tentative forms of balance*. These forms of balance are appropriate only in certain historical period. In contrast, the cause of sustainable development will be a dynamic process, which will constantly reconcile new contradictions after the old ones are resolved.

In the current historical period, the situation is as follows: in developed countries, the major contradiction is between sustainability and over-consumption rooted in the modernist conception; in developing countries, the desire for meeting human material needs and the low capacity of production constitutes the major contradiction. Moreover, the end of cold war, to some extent, suggests the triumph of capitalism over socialism (Slater 1995).

For developed countries, an appropriate economic system should therefore be one that will enable the maintenance of the capacity of production while keeping the economy within the carrying capacity of the earth. Daly and Cobb's proposal (1994 p59) on this issue is particularly insightful. The market is wonderful only in resource allocation. The issues of the *optimal scale of economy* relative to the ecosystem and the *just distribution of economic output*, both of which are of critical importance to sustainability, should be dealt with by collective will represented by democratic governments. These governmental interferences would *complement the market based economy, reconciling the inconsistency between the relation of production of capitalism and the ideology of individual-in-community*. A form of distribution that would be consistent with the new ideology, for example, is increased taxes on over-consumption of natural resources (including the atmosphere), and the use of the tax revenues either for natural capital investment or for increase in social welfare to reduce the disparity between the rich and the poor.

Economics aimed at serving such a system should put emphasis on the study of the carrying capacity of nature, the interaction between human and nature, the valuation of environmental damages, the analysis of sustainability and unsustainability (economic and environmental indicators), the substitutability of natural and human-made capital, and the investment in natural capital (Ehrlich 1994, Folke et al. 1994, van den Bergh and van der Straaten 1994a). In support of policy decision making, economics needs also to analyse costs and benefits of policy options. It should conduct this analysis in a larger context, one encompassing both economic and social goals, the human and natural habitat, and the present and the future generations. These analyses would inevitably deal with the

institutional and distributional elements in environmental policy, and the issues of environmental ethics and philosophy. Economics, therefore, must involve not only economics itself, but also such relevant disciplines as ecology, geography, political science, sociology and philosophy. The need for such a wide-ranging study imposes a great challenge, but it is precisely what ecological economics - a transdisciplinary study of economics and ecology - is attempting to do (Jansson et al. 1994, van den Bergh and van der Straaten 1994b, Peet 1992). Originated in the most recent decade and with a holistic worldview, ecological economics "seeks to constitute a true marriage of ecology and economics so as to give meaning and substance to the idea of sustainable development" (Jansson et al. 1994, van den Bergh and van der Straaten 1994b). The two sidedness of sustainable development - the need for quick actions and the requirement for considering long term, large scale issues - have resulted in two streams of thoughts in its development. On the one hand, quite specific and seemingly operational plans for policies and instruments are proposed, which connect ecological economics with environmental economics (Bromley 1995, van den Bergh and van der Straaten 1994a). On the other hand, a search exists for new frameworks, models and theory with regard to sustainable development problems, characterized by the use of a systems approach (van den Bergh and van der Straaten 1994b).

The development of ecological economics and continued scientific research of nature will increasingly improve our understanding of the issues of sustainability. However, the organismic ecosystem is so complex and fragile, and our understanding of it is, after all, very limited. With regard to natural resources, human ingenuity may eventually bring about a fundamental breakthrough of energy source - the most important resource to the human economy. But to date, it is uncertain. Therefore, a precautionary approach is essential in economic and environmental policies, as well as in our attitude to nature. The precautionary approach implies not only prudence in dealing with problems that are discovered but not fully certain (such as climate change), but also the strategy of reducing our impacts on the environment as far as possible. Limits to economic growth is an issue of particular relevance to the precautionary approach.

Theoretically, what is directly required by the precautionary approach is to limit resource consumption. Constraints to economic growth may result from this limitation, but an adequate theory or evidence is lacking to support the argument of limiting economic growth as a strategy of sustainable development. In fact, it is because there is great potential for reducing resource throughput through resource efficiency and substitution that the mainstream approach appears to be attractive. In the short term, a large potential lies in the reduction of the current over-consumption of energy, water, and other commodities such as wood- and metal-made products. In the long term, substitution of non-renewable and polluting resources with renewable and clean resources has great potential. An example is the substitution of oil and gas with solar and hydroelectric energy for electricity supply. At the same time, technological innovation should be geared toward low resource intensity, more reliance on renewable resources, and environmental friendliness (Schumacher 1973, Daly and Cobb 1994, Thomas 1995). Governments should also promote the development of less resource intensive industries, while limiting economic activities with high resource cost. Thus, Western countries could still seek growth, but the *growth should be selective and resource throughput should be stabilized* - so called steady state economy - *or even reduced*, with the economic structure modified in favor of resource efficiency and renewable resources.

To this end, in parallel with moral education, a wide range of public policy measures are necessary (Costanza 1994). Among others are such economic instruments as environmental taxes, resource quota, levies and fiscal incentives. These often need to be used in combination with command and control tools to improve the effectiveness. Local communities should emphasize programs of reuse, recycling and reduction. Of particular importance is the provision of information to citizens with regard to products, consumption and environmental issues. A holistic vision is crucial in the design of environmental policies and programs. Citizens should also be informed about the larger picture, as practiced in the Netherlands, to increase their confidence in the programs and thereby improve their participation. At the same time, effort should be continued to revise the indicator of economic welfare to including natural resource depletion.

The potential of resource efficiency and substitution, however, does not remove limits on the physical scale of the economy resulting from finitude, entropy and ecological dependence (Daly and Cobb 1994 p199). After all, the planet is finite in both its resources as the input to human economy, and its sinks to absorb the wastes from human economy. The best index showing this finitude is probably the percentage of human appropriation of the total product of photosynthesis of the planet - a measure of renewable resources. According to Vitousek et al. (1986, cited by Daly and Cobb 1994 p143), 40% of terrestrial net primary production (NPP) is now appropriated by human beings. If per capita resource consumption remains unchanged, the percentage of human appropriation would be doubled in 40 years according to the projected demographic growth. A 100% human appropriation would leave no energy for nonhuman and nondomesticated species. This is an impossibility since humans cannot survive without the life support system, which is made up by all other species (Daly and Cobb 1994 p144). Therefore, moral education must go in parallel with other policy instruments, in order to encourage citizens to consume less while leaving more for those whose basic needs are not yet met and those who are yet to be born. It is also a necessary preparation for citizens to accept the reality of no growth when it eventually results from the controlled resource throughput.

In principle, this form of economic system with both the market and planning as its major elements, and a precautionary approach as a primary principle, is applicable to developing countries as well. The difference lies in priority. For developing countries, in general, priority should be given to economic development aimed at meeting human's material needs and alleviating poverty, and to population control in order to reduce the potential demand for resources. Also, self-sufficiency and community development are of particular importance for survival of the poor. The development, nonetheless, should as well proceed with sufficient consideration of environmental objectives.

The economic system as so defined will be subordinate to social goals, rather than the reverse, and economics in service of such a system will be closer to *oikonomia*, rather than to *chrematistics*. *Oikonomia*, according to Aristotle (Daly and Cobb 1994 p138),

refers to "the management of the household so as to increase its use value to all members of the household over the long run". The concept of household, in the context of environmental sustainability and individual-in-community ideology, extends to the entire biotic communities, including both the human and nonhuman beings, and the present and the future generations. The economic system and the economics are thus both reductionist and holistic. They are reductionist because they make use of the market as well as the market theory; they are also holistic in that they give considerations to the welfare of the entire earth community.

4.4 Institutional Reform - Searching for A Holistic Framework

To effect the changes in worldview, ethics, values, political philosophy, economic system, as well as economics, the institutions established under the modernist conception needs reform. Reductionism has been exclusively applied to all aspects of institutions, be they the Western or Eastern, the North or South. While reduction is inevitable in order to make matters manageable, what is required is an institutional reform with the integration of reductionism into a holistic framework.

The issue that has drawn wide attention in regard to institutional reform is that of decentralization versus centralization. To keep the economy within the earth's carrying capacity, we need to limit resource throughput. It commands a centralized control. However, sustainability is after all a normative principle. Citizens should not only participate in the implementation of the actions, but also in the process of sustainability policy decision making (Robinson et al. 1991). This entails the decentralization of powers to the level of public administration that is pertinent to the policy decisions, and that enables the widest public participation. For many decisions, local government or community is found to be the appropriate level. Such participatory democracy would also empower citizens and enable them to realize that their activities and attitudes help to shape "consensus reality" (Thomas 1995). Citizens so empowered would be more active, creative, and responsible, for their life as well as for the cause of sustainability.

The concept of community is of great importance. Community emphasizing non-mobility of population and self-sufficiency in economy, as proposed by communalists, raises many questions. Instead, community should give priority to participatory democracy. It should also, through diverse activities, promote the ethics and values of individual-in-community, facilitate the development of social relationships, and provide social services for those who need special cares.

The jurisdiction of local government is another issue deserving special consideration. A widely appreciated alternative to the current jurisdictional system is bioregionalism. It is based on the idea that economic, social and political life should be organized by regions that are defined by nature, not by legislature. The wholeness of an ecosystem, for example, can be better managed by a single government in a holistic manner, rather than by multiple ones that each take up a portion of it. Regions as so defined would also give society many nonhomogeneous situations from which to derive its practices and institutions. Our society, as well as the environment, would therefore have more chance to sustain than the current one (Thomas 1995). The transformation from the current system to a bioregional one, of course, would involve enormous reform. New Zealand, however, has put the idea into practice since 1991 (Johnson 1995 p68). The recently enacted law, the Resource Management Act (RMA), entirely restructured the country's resource agencies according to watersheds, with the aim at sustainable resource management. This law, based on a remarkably thorough public review, has received wide support from the citizens.

The reduction of governmental functions into separate departments is a necessary approach to any government. The implementation of the principles of sustainability, however, requires that a holistic view be maintained in the entire administrative system. In particular, sustainability objectives should be integrated into policy decision making in all related departments, and the issues involving multiple departments should be adequately dealt with by appropriate institutions.

The nation state, from the perspective of the entire biotic community, is a form of reduction as well. Nationalism as proposed by Daly and Cobb (1994 p209) is individualistic in this sense. The wholeness of the ecosystem entails holistic coordination and cooperation between nations, especially between the South and North. Internationalism is therefore preferred to nationalism. It is probably true that the South, especially the least developed, did not gain much benefits from the economic interactions with the North in the past decades. *The problems, however, lie in nationalism rather than internationalism.* In particular, only by improved terms of trade and aid that are indeed aimed at poverty alleviation and technology assistance can we expect a globally joint action toward environmental sustainability as well as intergenerational and intragenerational equity.

4.5 From Reductionist Science to Holistic Science - The Emerging Scientific Paradigm

Science, including all social, natural and technological sciences, has provided a driving force for the entire Western civilization. It is of equal importance for the cause of sustainability. However, modern science, characterized by reductionism, is inadequate in meeting the challenges of the holistic issues of sustainability. Fundamental changes are needed in order to extend the scientific paradigm to include holistic characteristics. Among the most imperative are the extensions of the aim, approach and method of scientific inquiry.

As discussed earlier, modern science reduces the aims of scientific inquiry into knowledge and innovation. With the doctrine of 'value-free', science as so defined may greatly benefit humanity, as evidenced by scientific achievements and technological wonders. But it is equally possible to cause problems to humanity as well as the whole planet, as also evidenced by the nuclear disasters and the contemporary environmental crisis. The cause of sustainability entails the orientation of scientific inquiry to wisdom (Maxwell 1984 p66). While knowledge production is necessary, scientific inquiry aimed at wisdom will direct its priority to the examination of what sustainability means, what is

of value to humanity, what are the real problems facing sustainability, and how to solve the problems, to realize what is of value to humanity, and to achieve a sustainable world. Technological innovation, under such orientation, will be mainly directed to serving humanity as well as its harmony with nature, namely appropriate technology. Advanced technology as a symbol of human ingenuity could be developed, but it should be under close scrutiny with regard to its effects on humanity as well as the environment.

The general approach to scientific inquiry in modern science is reductionism. The whole intellectual paradigm, as manifested in the structure of the university, is reduced into individual scientific disciplines, each of which is further reduced into fields. Individuals working on such specialized fields usually know little about the larger context, the position of their fields within this context, and the potential impacts of their work on other fields. It is thus not surprising to find that while environmental scientists are researching the toxins harmful to human health, some chemists are pouring tons of chemical wastes into the environment without considering their impacts on the biotic community. In the quest for solutions to sustainability, such a specialized system leads to narrowly canalized lines, which block "the fresh approaches that are needed and places those who undertake them on the defensive before the authority of the disciplinary mainstream" (Daly and Cobb 1994 p363). Sustainability entails a holistic approach as a complementary extension to the reductionist approach. A holistic approach implies that scientists should have a clear view of the large picture, in order to maximize their capacity to serve human wisdom rather than merely curiosity or personal achievements. The holistic approach appreciates the systems perspective, emphasizing interdisciplinary and transdisciplinary enquiry into the interfaces and interactions between disciplines, and their relations to society and nature. Also, it requires that any disciplines or fields related to the environment and sustainability issues should incorporate these issues into their research agenda; mining, chemistry and civil engineering are some examples. Corresponding reforms should be carried out in the scientific institutions as well as the educational programs of the university, so that future generations will be educated within a holistic framework, and thus be better armed to pursue the cause of sustainability.

Also, modern science reduces the reality into the "subject" and the "object". Empiricism is then used as the standard method of scientific inquiry. Empiricism maintains that meaning postulates constrain scientific language, and observations generate observational reports that confirm or reject scientific hypotheses (Ayer 1991). In such a scientific paradigm, inquiries based on the methods other than the standard one hardly deserve to be considered from an intellectual standpoint (Maxwell 1984). By contrast, the organicistic worldview as the underpinning of the cause of sustainability entails pluralist methods for knowledge production. The standard method is most suitable, and performs well, for the problems which can be well defined and abstracted, and in which the boundary between the "subject" and the "object" is relatively clear. However, it must be acknowledged, as Raskin points out (1987 p268), that

- 1) empirical descriptions are limited, for what we see and how we describe the world is filtered through the screen of preconceptions, needs, and the social framing system in which a particular piece of research is conducted and considered valid;
- 2) our conception of scientific laws change under different conditions according to what people see and choose to see;
- 3) over the long run, scientific knowledge tends to yield different emphases according to identities of knowledge workers; and
- 4) the possibility of proof are limited even if we were to move to widen the screen of consideration, thereby moving from a problematic mode of inquiry to a dialectical or organic mode.

These points are particularly true for the problems of sustainability. Moreover, the traditional knowledge generated through generations of practice in non-Western societies, in many cases, have (or had) enabled the sustainability of those societies for centuries. This historical tradition of knowledge production (Redcliff 1992), along with such post-positivistic approaches as the hermeneutic method, participatory research, and discourse deconstruction and reconstruction, should all be appreciated in the postmodern scientific paradigm.

A dilemma may rise out of the seeming conflict between the current inquiry for sustainability, and the postmodernist thought of knowledge production. Postmodernism questions the unitary nature of the modern human subject, and rejects modernism's belief

in quantification as the defining character of the real, and totalizing and essentialising as the way of knowledge construction (Bordessa 1993, Cloke and Alder 1991, Frodeman 1992, Relph 1991). According to postmodernism, knowledge constructed in such a discourse serves power rather than truth. There can only be "local narrative communities" which have local knowledges and local truths, rather than Knowledge and Truth. The postmodernist emphasis, therefore, is to avoid the domination of modernism by deconstructing discourse and "celebrating" difference, multiplicity, and openness. In relating to sustainability, the search is for local sustainabilities, rather than sustainability. A question then arises: should we, or do we, have a common moral ground for the pursuit of sustainability (or sustainabilities)? The answer seems "no" to postmodernism because of its radical respect for difference. Given the global nature of sustainability issues, however, this answer is questionable.

Ethics are a contractual consensus among moral agents. They are grounded on ontology which explains nature, human, and human-nature relations, and further on cosmology which elaborates the origin of the universe as well as human beings. Therefore, the existence of diverse religions, originating from different nations across the world, has historically helped formulate different ethics. Most noticeable are the variety of Eastern ethics sharing an emphasis on self-restraining, altruism, and identification with nature, the Christian ethics characterized by loving, caring and responsibility, the Western intellectual tradition distinctive in individualism, human rights and respect for others, communist ethics giving the greatest moral concern to community, and tribal ethics emphasizing co-existence with nature. Although with some consistency and overlap, these ethics are by no means identical. The consistency and overlap have brought nations together in pursuing the common good of humanity. The differences have played a role in culture formation on the one hand, and have been a source of conflicts between nations on the other hand (for which the human right issue may serve the best example). Despite the pluralistic forms of ethics, humanity has survived throughout its history, with diverse cultures survived and many of them flourishing.

The challenges of environmental sustainability, however, impose the need for a set of globally shared ethical principles. This is because of the particular problem we are facing - the environmental crisis within the interrelated, finite global ecosystem. The problem is further complicated by the large discrepancy of standard of living between different nations: it is neither possible nor fair, for the poor to sacrifice their survival rights for environmental sustainability; it seems equally difficult for the rich to stop pursuing an even richer life. Without a holistic worldview and a set of general ethical principles agreed to by all nations, sustainability would remain a dream. Therefore, sustainability, as a declaration of the highest principle of humanity, is non-pluralistic, so are critical sub-principles derived from this principle, such as reducing resource consumption and environmental benign behaviors.

Conclusions of Part I

Sustainable development as the highest principle of humanity attempts to reconcile the contradiction between development and the environment. The causes for the environmental crisis can broadly be generalized into the inappropriate mode of production, over-population, poverty, and over-consumption. All these causes, however, are to a different degree rooted in, or related to, the conception of modernism with regard to worldview, ethics, political ideology and economic system, all characterized by reductionism.

To pursue the principle of sustainability, four approaches are found to be relatively distinct, namely cornucopian, mainstream, social ecology and deep ecology approach. The Cornucopian approach, which believes that the market and technology will provide all the solutions, is more likely to worsen the problems than to solve them. The mainstream approach, characterized by an adaptation of its current institutions to accommodating the environmental objectives, may do relatively well in improving resource efficiency and promoting resource substitution. But it is inadequate in steering humanity toward a sustainability path, since it cannot tackle the problems of consumerism, over-population, and poverty - the problems deeply rooted in modernism. With the recognition that the environmental problematique stems from modernism, social ecologists emphasize the need to address the complex issues of political economy, and propose communalism as an alternative to both capitalism and socialism. Communalism, which emphasizes relative self-sufficiency and central planning for resource throughput, offers promising features for leading society toward sustainability. But its side-effects, such as the reduced possibility of meeting human aspirations, and the increased possibility of developing countries repeating the Western process of industrialization as well as the pollution, make this approach questionable. The most radical approach is deep ecology, which envisions a society dealing with environmental ends through both close regulation and individual's spiritual revolution, namely Self-realization. Self-realization as a norm of deep ecology does point to one of the directions to which human

spiritual growth should be directed. However, biocentric equality as the other norm of deep ecology reduces the coherence of the theory, keeping it far away from practice.

In an attempt to overcome these weaknesses, Chapter 4 of Part I, based on recent insights in philosophy, ethics, economics, and scientific inquiry, has articulated an alternative characterized by a coherent integration of the quintessence of the Western and Eastern civilizations, namely the reductionist and the holistic approaches. It suggests that it was by reductionism that humans are separated from nature, and that human societies are reduced into individuals. Individualism, the symbol of modernism which legitimates self-interest and leads to industrial competitive materialism, impedes any solutions attempting to address the issues of sustainability, particularly over-consumption, over-population and poverty. To remove this impediment entails a shift from scientific, reductionist materialism into the rising, holistic worldview, which recognizes the planet as a unified, dynamic and organistic system in which humanity is only a part.

This worldview implies the intrinsic value of the earth ecosystem, as well as its vital importance for all living beings. It also implies a universal morality which imposes an obligation to respect the needs, and to foster the welfare of, the entire earth biotic community, including both humans and nonhumans, and the present and the future. Individualism as the basis of ethics and political ideology is thus invalidated, with the substitution being individual-in-community. Individual-in-community is holistic in that it stresses the interdependence between individuals and the community; it is also reductionist in that it acknowledges the rights and benefits of individuals. These rights and benefits, however, become constrained in a community context. From the individual-in-community ethics and political ideology, a set of social values can be derived; of particular importance are loving, caring, cooperation, democracy, and social and environmental responsibility. These values, along with the values of talents in art, craft and sport, and self-cultivation in literature, philosophy, and aesthetic, should replace the modernist value of industrial competitive materialism, redirecting human competitiveness towards human harmony with nature.

An economic system consistent with the individual-in-community ideology should then have two major elements: the market for optimal resource allocation by making best use of individual knowledge - a reductionist component; and the planning of resource throughput and income distribution for intergenerational and intragenerational equity, as well as for the welfare of nature - a holistic approach. Ecological economics aimed at a true marriage of ecology and economics may provide the best insights for the management of such a system. While there exists great potential to improve human management of natural capital and the human economy, human understanding of nature is, after all, very limited. A precautionary approach is therefore of particular importance. Policies of resource efficiency and substitution may lead to considerable reduction of resource throughput; but they are inadequate. Governments should also engage in the stabilization and even reduction of resource throughput, and in restructuring the economy in favor of low resource intensity and renewable resources. The limitation of resource throughput may eventually constrain economic growth. Comprehensive environmental education programs must therefore go along with such sustainability endeavors.

While resource throughput should be centrally determined, the normative nature of sustainable development entails the decentralization of political powers to the levels of administration that are both appropriate for the nature of policy decisions and suitable for the public participation in policy decision making. Also, community development is of great importance in facilitating participatory democracy and organising social activities to allow for self-development and mutual caring. In parallel with all these changes should be the integration of a holistic approach into the modern, reductionist scientific paradigm.

There had never been a moment in the history of humanity when all members of the human community had to work together for the common good. The declaration of sustainable development as the highest principle of humanity has given rise to such a moment. This moment will endure as long as humanity sustains. It will give rise to a dynamic, evolutionary process propelling humanity forward. This process is expected to give birth to an equable, diverse, and prosperous human community in true harmony with nature. This birth, however, will be a tremendous challenge.

Part II

Role of Geomatics in Sustainable Development Policy-making

Introduction to Part II

The transformation of modernism, however, will not take place in the short term. A realistic strategy is to seek immediate, tentative solutions to the problems already identified while exploring the longer term possibilities at the same time, rather than to be fully committed to the ultimate solutions. The mainstream approach to sustainable development, as practiced by United Nations through Agenda 21, as well as such countries as the Netherlands and Canada, to a great extent, are examples of the short term approach (Environment Canada 1999 p18). This approach emphasizes the importance of economic growth while stressing environmental sustainability. The core apparatus of this approach is public policies, supported by scientific information.

In general, the scientific information required for sustainable development policy-making has two important dimensions: space and time. This is because, spatial distribution and interaction constitute the fundamental characteristics of the environment and humanity, as well as the interaction between them. Meanwhile, sustainability implies temporal durability.

Geomatics is an evolving discipline that addresses a range of issues dealing with geospatially referenced data, including geospatial data acquisition, transformation, management, analysis, visualization, distribution, and the methodology of application. It is the result of a merger between several independent and older disciplines including geodesy, photogrammetry, land management, cartography, and more recently, geographical information science and remote sensing. Geomatics, therefore, has the potential to contribute to the process of policy-making toward sustainable development.

This part of the thesis is devoted to the exploration of this potential. First of all, the processes of sustainable development policies and policy-making are analyzed in Chapter 5, with climate change used as a case. The following chapter examines the general characteristics of the policy-making process in relation to the spatial dimension, as well as the challenges arising from them. The existing roles of geomatics in meeting these challenges are examined in Chapter 7, with the potential and opportunities for geomatics to further address these challenges identified in Chapter 8. Based on the analysis of the potential and opportunities, the Chapter 9 proposes an integrated solution to substantially advance the role of geomatics in sustainable development policy-making.

Chapter 5

Sustainability Policy Process and Policy-making: The Case of Climate Change

The policy process is a dynamic, cyclic and complex one. Policy researchers have devoted a great deal of effort to the characterization of this process (Howlett and Ramesh 1995). The resultant models differ from each other. However, it is generally accepted that a policy process can broadly be described in a six-step framework: problem identification, agenda setting, policy formulation, decision making, policy implementation, and evaluation. While it generally fits into this framework as well, the policy process of sustainable development can be characterized more pertinently, as shown in Figure 5-1.

Figure 5-1: Sustainability policy process and policy-making

Policy-making, as a major issue of concern for this thesis, normally involves the sub-processes of agenda setting, policy goal formulation and policy action formulation. In the context of this thesis, however, it is extended to also include problem identification, the sub-process that is closely related to sustainability policy formulation. This section addresses each sub-process of policy-making, with a brief account given for the remaining processes for a complete discussion of the policy process. An emphasis is placed on information related issues, as geomatics deals with information. The policy issue of climate change is used as an example.

5.1 Problem Identification

A policy process usually starts with the identification of problems requiring societal action. In the context of environmental sustainability, the problems deal primarily with the environment, including the environment as natural resources, sinks and life support systems. The initial diagnosis of such problems usually originates from the scientific community or environmental non-governmental organizations (ENGO). The prime actors are therefore scientists and environmentalists who have access to information on the problems. Multiple steps are normally involved in the identification process, including the detection of changes, the identification of causes, the prediction of changes, and the assessment of impacts (Taylor and Buttel 1992). The evolution of these research activities has given rise to a new scientific discipline – earth system science (NASA, 1999).

For change detection, long term, consistent, and reliable observational data are required for the identification of the significance of change. As environmental changes usually involve long time-scales, and long-term historical data are often unavailable due to the unpredictability of environmental problems, various proxy data are often used in assistance of change detection. In the case of detecting global warming, quality, spatially-referenced time series data for global temperatures, acquired from satellite systems, surface measurements and weather model outputs, are used to detect changes in the past century, as well as in the recent decades (Schneider 1994). Temperatures from boreholes and tree ring records are further used to improve the successful separation of transient long-term trend signals from data noise. For the paleo period, temperature records from ice cores provide proxy data for change analysis, supplemented with studies into past positions of sea pack ice edges, lake levels and salinity, monsoonal intensities, tree rings and alpine tree limits in various regions (Environment Canada 1999).

Once a change is identified and the impact of the change is conceivably a considerable one, a causal relationship analysis follows. The analytical approach involves inductive

hypothesis testing and deductive reasoning of the secondary causal relationships (Schumm 1991 p12, NASA 1996). In any case, quality time series data for the variables that are potentially related to the problem are required. To identify the causes of global warming, for example, significant efforts are made to differentiate natural variability, which results from such natural phenomena as random perturbations in radiative fluxes and ocean currents, from forced changes, which are due to such external forcings as an enhanced greenhouse effect. This is then followed by the analyses of subsequent levels of causes, such as anthropogenic greenhouse gas emissions as a contributor to the external forcing and their sources. Enormous amounts of data are involved in this analytical process, ranging from atmospheric, oceanic, and terrestrial, to socio-economic (NASA 1996).

The analysis of causal relationships, subsequently, allows for the development of models for the prediction of future changes (Schneider 1992). The trend of modelling is to develop comprehensive, highly accurate, highly detailed natural-systems models that are potentially predictive in the traditional scientific sense (Edwards 1996). Termed earth system modelling, this modelling effort plays a central role in earth system science. The primary modelling techniques can be grouped into two types: process-driven and data-driven. The former usually results in deterministic models, and the latter in probability or statistical models. Models are validated usually by simulating past as well as current situations.

Climate change modelling is essentially the origin of earth system modelling. It has evolved from atmospheric General Circulation Models (GCMs) to coupled oceanic and atmospheric GCMs (OAGCMs) (Meehl 1992). The goal is to further couple models of other climate-related systems, such as land surface, to an OAGCM, eventually capturing all of the major elements of the total climate system – including greenhouse gas emissions from anthropogenic sources (Edwards 1996). Based on these models, temperature and precipitation over the globe are predicted at 1 km grid spatial resolution (Environment Canada 1999). Sophisticated models of socio-economic activities, however, have been last in line for integration into climate change models (Edwards

1996). With the absence of such sophisticated models, predictions are often performed based on the doubling CO₂ scenarios. Climate changes at higher resolutions are predicted, either based on regional climate models that can be economically run to incorporate local influences on climate, or through down scaling techniques relative to the GCMs they are linked to (McGregor 1997).

The final step of sustainability problem identification is the assessment of the potential impacts of a problem. This is a critical step for the subsequent processes of policy-making, as policy actions are taken only if a problem could potentially create significant negative impacts on social, economic and environmental systems. The potential areas for assessment hence cover all the areas that may receive impacts. In the case of global warming, assessments have involved the direct effects of CO₂ increase on ecosystems, and the impacts of global warming on hydrology, natural ecosystems, agriculture, cryosphere and sea level. Efforts have also been made to assess social impacts of climate change, including the vulnerability of societies in response to climate change, the economic cost of climate adaptation, and the health effect of climate change (Dowlatabadi 1997, Environment Canada 1999). In a case study of Canada's Mackenzie Basin, a comprehensive assessment has been carried out to take all the impacts into account (Cohen 1997).

Uncertainty is an integral part of any predictions. In general, the more complicated the system being modelled, the more variables and equations the models need to include. As a result, the model would have a lower accuracy, and the resultant predictions would bear a larger uncertainty. Uncertainties are therefore unavoidable with any predictions produced by earth system models, so are the impact assessments that use the uncertain predictions as well as assessment models. Climate change prediction is typically such a case. Uncertainties exist in the predictions of warming rates, as well as the processes that cause warming.

5.2 Agenda Setting

The agenda is the list of subjects or problems to which governmental officials, and people outside of government closely associated with those officials, are paying some serious attention at any given time (Kingdon, cited by Howlett and Ramesh 1995 p105). It can be differentiated into two types in the context of sustainable development: the agenda consisting of all sustainability issues that are commonly perceived by members of the political community as meriting public attention – the so called public agenda; and the agenda for public policy actions - so called formal agenda. Agenda setting is thus the process through which the issues of sustainable development move from the public agenda into the formal agenda. The primary actors in this process are the group which has identified the problem, the media, the ENGOs, the industries and individuals directly affected by the problems, and through them the concerned public.

Typically, in the liberal pluralist societies and the international political communities, a sustainability issue is first initiated by an “epistemic community” – a knowledge-based professional community that shares a set of values, beliefs and practices for environmental problem identification (Haas 1990, Edwards 1996). Earth system models, predictions and impact assessments serve as a basis for building consensus on a particular problem within the epistemic community. With consensus reached, this community then attempts to expand support for its demand, which may lead to the formation of alliances across groups. These groups together lobby, contest, and join with others in order to get the expanded issue onto the formal agenda. “If they have the requisite political resources and skills and can outmaneuver their opponents or advocates of other issues and actions, they will succeed in having their issue enter the formal agenda” (Howlett and Ramesh 1995 p113).

In the case of climate change, the epistemic community involves climate and paleoclimate science, oceanography, ecology, energy modelling, economics, agronomy, and a variety of other sciences (Edwards 1996). While uncertainties remain, this community predicts with a high confidence level that: global warming is unavoidable;

risks of danger become high for global warming exceeding 2°C; and this degree of warming could result from a doubled CO₂ concentration in the atmosphere, which may take place in the middle of the next century (Environment Canada 1999). The International Panel on Climate Change (IPCC), as a representative of this community, initiated consideration of this issue by the international political community (IPCC 1990). At the same time, this epistemic community expanded the issue through a variety of publications. The media and a wide range of ENGOs then joined the group, further spreading the information among policy makers as well as the general public. The increasing scientific certainty, and the worldwide concerns raised about the potential irreversible consequences and impacts of global warming, finally pushed the issue to the formal international agenda. The International Framework Convention for Climate Change (UN 1992c), the international commitment to greenhouse gas reduction signed by over 150 countries, marked the success of this process.

5.3 Policy Goal Formulation

Once an issue is on the formal agenda, a policy community is then engaged in the process of policy formulation in order to address the issue. In dealing with sustainability issues, this process can be characterized into two-steps: the formulation of policy goals, and the formulation of policy actions for the implementation of the goals. The primary actors for the former step are normally the international political communities, consisting of the heads and relevant ministers of all the countries that have agreed on Agenda 21 - the United Nations' initiatives toward sustainable development (UN 1992b).

A quantitative tool in support of this process is integrated assessment models. The standard view of integration refers to the causal chain that joins human actions to valued consequences (Edwards 1996). This, to some extent, resembles the goal of earth system modelling (Edwards 1996). Unlike earth system models, however, integrated assessment models are clearly oriented to supporting sustainability policy decision making, especially the formulation of international policy goals, rather than advancing the understanding of the earth systems (CIESIN 1995). The idea is to offer policy makers an

effective way to learn a set of heuristics – a quasi-intuitive “feel” or rule of thumb based upon, yet not fully determined by, data-driven analysis – for sustainability policy options (Edwards 1996). To do so, Edwards notes that the modellers are typically engaged in rough, order-of magnitude modelling which attempts to be comprehensive only in those areas most directly related to human activity, such as energy and agriculture. The models incorporate empirically derived trends, heuristics, and unproven or qualitative theories into their modelling techniques far more freely than do earth system models. Their goal is comparison of policy scenarios and forecasting of trends, not prediction at statistically significant levels.

As countries differ significantly in their current development as well as historical experiences, the policy goals addressing sustainability issues often need to vary with countries as well. Conceivably, this process can be extremely complex, involving intensive conflict resolutions and trade-off negotiations (Parson and Zeckhauser 1995). The policy goals resulting from such negotiations are often modest. The relevant countries usually undertake national level assessments before their ratification of the goals.

In the case of climate change, policy goals dealing with greenhouse gas reductions are formulated by the international political community coordinated by the United Nations, with decision makers representing most countries sharing the same concerns. Ideally, integrated assessment models supporting the formulation of policy goals should consider the social and economic factors that drive emissions, the biogeochemical cycles and atmospheric chemistry that determines the fate of emissions, the resultant effect of emissions on climate globally and locally, and the impacts of climate change on managed ecosystems, and consequently on human activities and welfare (CIESIN 1995). In practice, however, none of the integrated models are fully integrated (Leemans et al. 1996, Swart et al. 1995).

Currently, the most advanced integrated assessment model in use appears to be IMAGE2, an Integrated Assessment Model for Global Change developed by National Institute of

Public Health and the Environment (RIVM), the Netherlands (UNEP/RIVM/PE 1997). With fully linked energy, land use, and ocean-atmosphere sub-models, this model has been used in support of the formulations of international climate change policy goals, including both the International Framework Convention on Climate Change and the Kyoto Protocol (Leemans et al. 1996, RIVM 1997, UNEP 1997a). Critical thresholds of weather and climate variables are identified using the models, including their means, extremes and rates of change, beyond which impacts on ecosystem and societies become problematic. Based on these thresholds, the amount of greenhouse gas reductions required in order not to exceed the thresholds are estimated. While uncertainties remain, these estimates provide a rough reference for the formulation of international climate change policy goals (CIESIN 1995).

Greenhouse gas emissions, as primary results of energy consumption, however, are closely related to economic growth. The developing countries argue for not participating in the immediate reduction action, because of their imperative needs for economic development. Significant impediments exist in Western countries as well, especially the U.S., in their commitments to the global action. As a result, the Kyoto Protocol - the current international climate change policy goals formulated in 1997 - only mandates, by 2012, emission reduction to an average of 5.2% below 1990 levels for the Western countries, far less than the minimum 50% reduction required to avoid the danger of global warming (Environment Canada 1999).

5.4 Policy Action Formulation

Once the international policy goals are set up, each country involved then embarks a formal process of policy action formulation for implementing the goals. Numerous countries may also work together for joint implementation. This process can be further decomposed into two sub-processes: policy option formulation and decision making.

Policy option formulation aims to identify policy alternatives for implementing policy goals and assessing their consequences. In the Western democratic countries, this

process usually includes three major elements: partnerships among all levels of government as well as different government departments involved; consultations with a broad group of stakeholders, ENGOs, different interest groups as well as citizens; and policy analysis for the identification of policy options and the assessment of their cost, benefit and impact (NRCan 1999b). Policy analysis generally involves a range of issues, including the major sources of the problem in particular areas, the changing trends, the policy options to tackle the problem, and the cost⁶ and benefit of the policy options. The assessment of the potential impacts of the policy options is of great importance as well, because of the need to integrate social, economic and environmental considerations in sustainable development policy decisions. While existing information and knowledge may serve as important sources, models play an important role in the analytical process.

Based on the formulated policy options, policy decision makers then evaluate each option and make final decisions (Howlett and Ramesh 1995 p141). Decision makers are usually a hierarchy of government officials and politicians representing corresponding jurisdictions (NRCan 1999). The decision making process is often a complex, hierarchical process, taking a long time, involving many policy document revisions, and resulting in a much smaller set of alternatives for action than initially formulated.

For the issue of climate change, the countries ratifying the Kyoto Protocol are subsequently engaged in the development of implementation plans. In Canada, for example, the Energy and Environment Ministers at the federal and provincial levels are charged with the development of the National Implementation Strategy on Climate Change, in order to achieve the policy goal of greenhouse gas reduction (NRCan 1999). Sixteen stakeholder committees of limited size, called Issue Tables, are formed for the formulation of policy options. Some of these Tables deal specifically with energy use sectors, such as transportation, energy production, buildings, forestry and agriculture. Others address the policy issue from generalized perspectives, such as municipalities, public outreach, and modelling and analysis. Table members are stakeholder

⁶ It should be noted, however, that the analyses of cost and benefit are extremely difficult for sustainability policies, due to the broad scales that the issues involve.

representatives drawn from government, industry, ENGOs, and other organizations and interest groups. Each Table is responsible for consulting a broader group of stakeholders who have an interest in the Table's sector or issue. With expert subcommittees formed under each Table, the Tables have each developed Foundation Papers which identify the current status of the issue as well as the needs for research (Government of Canada 1999). In cooperation with the Modelling and Analysis Issue Table, which is responsible for quantitative assessment, each Table has further developed an Option Paper that identifies opportunities for immediate and longer term actions, along with their cost-benefit analyses (Government of Canada 1999). The recommendations made by Issue Tables are then consolidated by the National Secretariat on Climate Change - a virtual office consisting of federal and provincial staff. The consolidated policy documents are then submitted to policy decision makers for decision considerations. The decision makers include a range of government officials and politicians, ranging from middle level officials to the Joint Meeting of Energy and Environment Ministers (JMM⁷). Action funds are finally allocated by the Treasure Board upon Cabinet's approval. Figure 5-2 illustrates both the policy option formulation and decision making processes, with an emphasis on the processes of policy analysis and decision making.

The quantitative goal of greenhouse gas reductions makes quantitative assessments essential for this policy action formulation process. Particularly, the Inter-Fuel Substitution Model (NRCan 1996a), developed initially for energy forecast in Canada, has been expanded for forecasting emissions of various greenhouse gases, based on a business-as-usual assumption. The baseline forecast is then used as the reference for assessing the effects of policy options proposed from the relevant Issue Tables. Some examples of such assessments are presented in Chapter 10, in Part III of the thesis.

5.5 Policy Implementation

Following sustainability policy decisions, agreed actions are put into effect. Governments are the primary actors in this process, with the level of government involved

⁷ JMM also provides ongoing advice on the preparations for continuing international negotiations.

Figure 5-2: Process of climate change policy making

corresponding to the scope of actions. Based on a defined policy measure or a set of measures, a specific program, or a set of programs, are created, with objectives, targets, and methodologies identified, and budget committed. The ultimate implementers of policy actions, however, are often relevant sectors, groups, or ordinary citizens, in the context of sustainable development.

5.6 Monitoring and Evaluation

Policy implementation is often followed by monitoring and evaluation, in order to assess the effectiveness and efficiency of policy programs. Scientists, resource users, observers,

governmental officials, and corporate managers are all the possible actors who generate information, and monitor the economic, social, environmental conditions and changes that occur in response to the chosen course of actions (Kumar 1993 p65). Policy evaluation is usually undertaken within the government, with its depth varying with the availability of resources, the level of difficulty for the evaluation, and the impacts of the evaluation. The increasing involvement of NGOs and the general public in the process of evaluation appears to be a trend in the cause of sustainable development (Johnson 1995).

Chapter 6

Characteristics and Challenges of Sustainable Development Policy-making in Relation to Geographical Space

Sustainable development as a policy issue has several important characteristics, which make the policy-making processes particularly challenging. In relation to space, this challenge is multifold. First, sustainable development involves the entire earth system in which all the components are interrelated; hence the needs for earth system modelling and policy scenario assessment, as well as for a tremendous volume of integrated information in support of the research. Second, the interrelatedness of the earth system manifests in the interactions not only between the different components of the earth system, but also between different locations. This spatial dynamics must be taken into consideration in the processes of modelling and assessment. Third, sustainable development as an ethical principle requires participatory democracy for policy decision making; wide access to information is therefore essential.

6.1 Broadness and Integrativeness

There has never been a policy issue in the human history that can be compared with the issue of sustainable development, in terms of the broadness and integrativeness it involves. Indeed, sustainability is concerned with the entire earth system, as well as the interrelationships between all its components.

The breadth and integrated nature of sustainable development issues makes modelling and quantitative assessment essential for policy decision support. While any models and assessments are uncertain and value-laden, in terms of the subject chosen for modelling and assessment, the methodology used, as well as the data acquired, they serve as an important approach to providing an overall framework of the linkages and interactions of the earth system, and to envisioning future scenarios based on this framework (Raskin et

al. 1997). In the absence of such a framework and visions, sustainability policy decision making would become baseless.

Modelling and quantitative assessments dealing with such broad and interrelated issues, however, present tremendous challenges. First and most prominently, the entire earth system, ideally, should be modelled and simulated in a holistic manner. *Integration should be expanded not only to causal chains (vertical expansion), but also to such different environmental sustainability issues as climate change, ozone depletion, land degradation, biodiversity and waste disposal (horizontal expansion) (Rump 1996 p42). It should even be expanded to other sustainability issues, such as economic sustainability and community sustainability.* While such high levels of integration, in practice, are far beyond human's current analytical capacity, due to the limitations in data, resources, and the understanding of the complex earth system, effort should be made in this direction.

To facilitate this process, it is fundamental to provide, and enable access to, adequate, well-integrated data that represent different components of the earth system. While the volume of geospatial data is growing rapidly, these data are often acquired by diverse agencies, using different standards and methods, under different spatial or thematic frameworks, and for specific purposes. As a result, their spatial and temporal frameworks are often inconsistent (Miller 1996). Access to these data are also problematic, due mainly to the ownership issue as well as the lack of data infrastructure. *Great effort is therefore needed in order to bring the tremendous amount of data under the same data management environment, reconcile the inconsistency between the data according to a common framework (such as ecosystem and grid), and make the data well integrated and accessible for all potential users.*

The second challenge lies in the need for the estimation of safe thresholds of the earth system for the understanding of sustainability. While it is fundamental, this estimation is largely beyond man's capacity as well. As a result, whereas research activities are currently observable in assessing such thresholds as the earth's carrying capacity (Erhlich 1994), the principal strategy for dealing with this challenge is to establish a cyclic process

of environmental monitoring, problem identification, and societal actions. Sustainability is thus seen as a dynamic process, in which attempts are made to keep human activities adjusted within the environmental limits.

The second challenge therefore becomes multifold. *One, a systematic environmental monitoring program needs to be developed,, to cover the entire planet at adequate spatial and temporal resolutions. Two, data acquired from the monitoring programs must be efficiently and effectively used for problem identification. And three, adequate policy actions must be taken timely in response to the problems.* Efforts are observable towards meeting these challenges. The United Nation's Global Environmental Outlooks (GEO) project is an example (Rump 1996 p99). With an emphasis on an iterative process of assessing progress towards the implementation of Agenda 21, the project aims at identifying emerging issues requiring policy attention through projection, scenario development and forecast, and supporting international policy setting and action through integrated assessment, informed decision making and enabling equitable participation (Rump 1996 p99, RIVM 1997). To make scientific assessments directly in support of policy decision making, *cooperative and frequent interactions between policy-makers and scientists are required* in the formulation of international policies.

6.2 Spatial Dynamics

In essence, sustainable development has to do with space, the fundamental dimension of the environment, human community, and the interactions between them. In particular, the environment is spatial: natural resources as the source of input to human economy is spatially distributed; most sinks that absorb the waste output from human society have a spatial property; and the life-support system has a spatial characteristic as well. Likewise, the human community, as part of the earth biotic community, is dispersed across the planet, with locality being an important attribute in its process of development, formation of cultures and interaction with the environment. Sustainability is essentially to enable the environment and diverse human cultures endure over time. Therefore, the

dynamics associated with space is an important characteristics of sustainable development policy decision making.

6.2.1 Spatial Diversity

One of the most important spatial characteristics of sustainable development is spatial diversity, namely the diversity between places. Spatial diversity results from dynamics within places as well as between places. The spatial patterns exhibited in the components of the environment and the human community, first of all, lay a basis for the formation of this diversity. The dynamic interactions between the components with different combinations of the environmental and social processes lead to diverse human-environment relationships in different places. Even with a similar combination of social and environmental processes, these relationships could be diverse as well, because different places represent different combinations of historical experience (Wilbanks 1994). Different external influences further compound the differences, resulting in diverse patterns of sustainability. Jones and Duncan (1996 p81) summarize the causes for the diversity as contextual differences, place heterogeneity, people/place interactions, individual heterogeneity, and changes of people and places.

Whereas the post-modernist radical emphasis on difference with regard to the sustainable development concept is questionable, it is, however, indeed valid to consider, under a widely accepted ethics for sustainable development, the spatial diversity of sustainability in the policy-making process. The reason is multifold. First, differences between regions or places should be respected from the ethical point of view. Totality based on generalized quantification is a manifestation of hegemony (Curry 1992). Countries at different stages of development, for example, should not be expected to give the same response to sustainability issues, because of their different historical experiences and different current standards of living. Second, the spatial diversity of ecological and social processes and their relationships leads to different priorities of sustainability in different regions or places, which must be addressed by corresponding policy actions. Third, international policy decisions towards sustainable development are essentially the outgrowth of intensive negotiations among countries. For democratic countries, national

policy decisions in turn depend on lower levels of administrations to a great extent. Any policies ignoring differences among the corresponding jurisdictions can hardly be put into practice. This is especially true given that sustainable development is in essence an ethical principle.

Respect for spatial diversity in sustainability policy-making entails that modelling and assessment in support of decision making be made explicit to regions or places. Like general geographical inquiries, sustainability research performed at different levels of geography likely result in different conclusions (Openshaw and Taylor 1979). A good example is the limits to growth studies conducted by the Club of Rome in the early 70's. The globally aggregate scenario forecast produced by the original world dynamics models reveals the danger of exponential growth in population and human economy (Forrester 1971, Meadows et al. 1972). The regional forecast as a result of regionally-disaggregate model runs, however, shows significant spatial diversity in regard to the danger, which provides more pertinent support to national as well as international policy-making (Mesarovic and Pestel 1974).

To support place-explicit policy-making, social, economic and environmental data should be collected at, or integrated to, the levels of spatial resolution sufficient for place-explicit analysis. Causal relationships, spatial patterns (such as spatial association, spatial autorrelation and spatial heterogeneity) and policy scenarios should be explored at these levels as well, to provide insights in support of policy-making.

6.2.2 Spatial Scale

The necessity to consider spatial diversity in sustainability policy-making raises a further question, namely the definition of regions or places in terms of spatial scale. Multiple factors appear to be related to this question, including the spatial scales of ecological processes which are more sustainable, of economic processes which are more viable for sustainability, and of human self-determination which are more appropriate for participatory democracy.

Ecological processes determine the scale of corresponding environmental issues (Rump 1996 p77). For example, climate change is primarily a global issue due to the ecological process of energy and radiation flows that operate at the global scale. The adaptation to climate change is mainly a regional or national issue, because of the regional difference in its potential impacts (Clark 1985). Land use practices, however, primarily affect local ecological processes; therefore, urbanization is mainly a local issue. Table 6-1 illustrates major environmental issues in relation to their ecological processes as well as *primarily* associated spatial scales. The delimitation of spatial scale in relation to the processes, however, is not without question in reality. In fact, as Levin (1993, cited by Aspinall et al. 1996) comments, the problem of pattern and scale is the central problem in ecology.

Table 6-1: Spatial scales, ecological processes and environmental issues (Adapted from Rump 1996 p77)

Spatial scale	Local	Regional	Continental	Global
Ecological processes	<ul style="list-style-type: none"> . soil formation . landscape restructuring . land use practices 	<ul style="list-style-type: none"> . regional climate . watershed hydrology . vegetation communities 	<ul style="list-style-type: none"> . tropospheric climate . biophysical evolution . wildlife migration 	<ul style="list-style-type: none"> . energy & radiation flows . high level air circulation . ecosphere hydrological cycles
Environmental issues	<ul style="list-style-type: none"> . erosion . urbanization . water pollution . waste accumulation 	<ul style="list-style-type: none"> . acid deposition . pesticide runoff . wetland loss 	<ul style="list-style-type: none"> . long range toxic transport . biodiversity 	<ul style="list-style-type: none"> . climate change . ozone depletion . deforestation . desertification

Interactions of spatial and temporal scales with each other and with phenomena at different levels of ecological organization determine the spatial scale at which ecological sustainability is more viable. Spatial scales delimited based on this understanding could provide a sound spatial basis for policy-making aimed at environmental sustainability. *Considerable study, however, is required in order to understand the interactions between pattern and scales and between processes that operate at different spatial and temporal scales.*

Spatial scale also constitutes an important dimension for the processes of economic development. Modern organization theory suggests that smaller economic organizations tend to be stronger while larger ones are less agile in sustaining through market changes (Wilbanks 1996). Likewise, sustainable economic entities, in the context of sustainability

policy-making, are sensitive to spatial scale. The dynamic interactions between different levels of spatial scale and between spatial and temporal scales, interwoven with environmental processes, make the sustainability of economic processes an extremely complex issue. Sustainable development as an endeavour to reconcile development and the environment requires that policy decisions are made at the level of spatial scales appropriate for both the environment and economy. *Extensive analysis and understanding of these interactions are hence of considerable importance in the determination of the level of spatial scale for sustainability policy-making as well as implementation.*

An additional factor that needs to be taken into consideration in sustainability policy-making is the geographical scale of the human community that facilitates participatory democracy, namely the participation by, and consensus building among, a broad group of policy players in the policy-making process (Robinson et al. 1990, Wilbanks 1996). A key to consensus building is personal communications, which are limited by time and spatial distance. Therefore, there are limits to the social and spatial scale at which participatory democracy can be fulfilled. This scale closely relates to the scales of ecological and economic processes. *Cross-sectional analysis of these scales and their interaction is therefore required in the delimitation of spatial scale for policy-making and implementation.*

The spatial scales appropriate for ecological, economic and political processes, however, are likely not to fit the existing spatial administrative frameworks. As Wilbank (after Bell 1989) comments, "our national boundary systems in many parts of the world are both too large and too small to handle such challenges as sustainable development: too large for the mediation of complicated issues to be handled in a participative manner and too small for the necessary resources to be allocated in ways that will get the job done". How to reconcile this scale conflict remains a challenge. *Studies on the interrelationships between these scales, however, can provide insights for improving policy decision making and political reform dealing with this conflict.*

6.2.3 Spatial Processes

Places or regions that are delimited by spatial scales are not isolated spatial entities. Instead, they are interrelated through constant spatial processes. Indeed, the entire interconnected global socio-environmental system evolves through space as well as time. Its economic, political, demographic, social, cultural, and biophysical subsystems, each and interactively, constantly form spatial flows, connecting all regions or places into a single earth community (Wilbank 1994). This connection is tightened through the current “megatrend” of globalization occurring in social, economic and environmental systems (Raskin et al. 1996). The driving forces for this trend include environmental processes, transnational institutions and trade, migration, cultural influence, geopolitics and global governance.

Spatial processes also occur, through time, within each social, economic, and environmental system, as well as their subsystems. Within the environmental systems, for instance, they occur between atmospheric, hydrologic, and ecological systems so that such macro-environmental systems as the earth climate are formed (Lee and Pielke 1996). As well, they occur within each of these systems, and help shaping the condition of each system (Moore 1996, Mladenoff et al. 1996). In essence, the sustainability problems of many environmental resources are measured in terms of spatial processes: deforestation, desertification, urbanization, and land degradation, to name a few.

Spatial processes are thus of considerable importance in the context of sustainable development. The simulation of such processes, especially through time, is an essential task in modelling and assessment aimed at sustainability policy decision support. To enable the simulation, a number of analytical tools are required. *First, spatial relationships (i.e. spatial adjacency) between geographical entities must be provided, to enable the definition of spatial characteristics of the processes. Second, the visualization of spatial relationships must be enabled, to allow the full use of analyst’s visual capacity in the analytical process. Third, a model-constructing environment should also be made available, to allow the modelling of spatial processes. Furthermore, the spatial characteristics of geographical entities should be appropriately stored in combination*

with time-series data, to allow for dynamic analysis of spatio-temporal processes. For the analysis of environmental processes, such information should further be *complemented with the third spatial dimension of an entity if applicable*, to enable the modelling and analysis of three-dimensional dynamics.

6.3 Participatory Democracy

An additional characteristic of sustainable development policy-making in relation to geomatics is the requirement for participatory democracy (c.f. Section 4.4). The policy actors should include all levels of government, non-government organizations, diverse stakeholders, and different social and interest groups (Robinson et al. 1990).

Of considerable importance to participatory democracy is equal access to information. Information that is properly structured and widely accessible will enable people to understand the “big picture”, and empower them both as policy participants and as implementers. Enormous amounts of information are involved in the sustainability policy process, including the states and pressures of the environment, the causes of the pressures, the business-as-usual scenarios, and various policy scenarios. *This range of information, along with policy programs and program evaluations, should be made accessible to all the participants in the policy process.*

Information as a result of monitoring, prediction and quantitative assessment, however, represents only one way of knowing the world, namely the scientific approach (Schumm 1991 p12). *Local knowledge as results of traditional way of knowledge production need to be incorporated into the information pool as well* (Clayton et al. 1998). Also, even with the same approach, different undertakings may result in different, even conflicting, information or knowledge, representing multiple understandings of the realities. In principle, *policy participants should be enabled to learn these “multiple realities” as well*, although political sensitivity remains an issue.

In response to the information, policy participants should be able to express their views through certain forums. The voices of different social groups, especially those marginalized by economic status, educational level, racism and sexism, should be adequately incorporated into the policy-formulation process.

The presence of multiple realities, compounded with the interests of different groups as well as their representatives, makes the policy-making process a remarkable challenge. Two distinctive, interwoven processes are usually embedded in this process: decision analysis and conflict resolution. The former, which involves the use of factual information and various policy scenarios to answer what-if questions, and the evaluation of policy alternatives according to multi-criteria, is more a rational process. The major practice of sustainability policy decision making is often the latter, a seemingly chaotic and irrational, social discursive process (Maguire and Boiney 1994, Gottsegen 1996). Gottsegen (1996) contends that sustainability policies tend to be the outgrowth of social interaction between opposing sides with different values and views of sustainability issues. This interaction is often antagonistic resulting in highly charged conflicts. Negotiations towards a common resolution usually involve the use of personal knowledge, or “commonsense knowledge”, that is constructed from values, experiences, affect, and meanings associated with a place as well as scientific information. The combination of such knowledge with differing interests of decision makers often makes the negotiation process extremely difficult. *It is a tremendous challenge to help decision makers to share these differing knowledges, negotiate compromising alternatives, and build consensus.*

Chapter 7

Current Role of Geomatics in Support of Sustainability Policy-making

The characteristics of sustainability issues in relation to space suggest that sustainability policy-making requires a range of spatial information support. Particularly, it includes the acquisition of earth observation data at adequate spatial and temporal resolutions, the integration of social, economic and environmental data into a common spatial basis, the dissemination of these data to relevant users, the analysis of geospatial data in terms of spatial diversity, spatial scales and spatial relationships, the modelling and simulation of socio-environmental processes in support of prediction and policy scenario assessment, the visualization of, and access to, spatial information for communicating sustainability information, and the support of policy negotiation in a group setting.

Geomatics is the unique discipline that deals specifically with spatial information. With the advancement of space technology and the increasing power of computers in recent decades, geomatics has encompassed two significant extensions from its original discipline of surveying and mapping: 1) the extension to a wide range of interdisciplinary studies, such as the monitoring of atmospheric systems, and renewable and non-renewable natural resources; and 2) the extension to provide theory, methodology and technology for geospatial data acquisition, manipulation, and integration, and for the subsequent analysis and visualization. The emergence of the science of remote sensing gave rise to the first extension, while the development of geographical information science led to the second extension. The most recent advancement in Internet technologies has offered geomatics further opportunities to information dissemination. Indeed, remote sensing, geographical information science, and Internet-based spatial information technologies have become the most active areas of geomatics research in recent years. As well, they are the areas of geomatics most relevant to the support of sustainable development policy-making. In addition, the global positioning system (GPS) represents another area of geomatics development that also has potential to contribute to sustainability policy-making.

7.1 Remote Sensing Complemented with Global Positioning Systems – A Unique Approach to Global Monitoring

Remote sensing has commonly been defined as the art and science of acquiring information through a sensory instrument without actually coming in touch with the area or objects being observed (van Wyngaarden 1998). From technological point of view, remote sensing denotes the joint effects of employing modern sensors, data processing equipment, information theory and processing methodology, communications theory and practice for the purposes of carrying out aerial and space surveys of the earth's surface (CIESIN 1995). Aerial survey is carried out by sensors equipped in aircraft, and space survey by sensors in space satellites. While photographs are part of the products, digital imagery is the principal outcome of remote sensing.

The Global Positioning System (GPS) is a satellite-based navigation system consisting of a network of 24 orbiting satellites (Dana 1999). Developed by the US military service, it provides a means to determine positions of any points on the earth with respect to the *geoid* - a mathematical function approximating the shape of the earth and anchored by the axis of rotation, the Greenwich meridian, and the centre of the earth. While the first GPS satellite was launched in late 70s, civilian GPS applications only started in the early 90's.

Remote sensing and GPS provide complementary means for global monitoring. They are also essential technologies for the acquisition of framework data that are needed for the registration of remote sensing imagery to the *geoid*. In the context of sustainability policy-making, they are making fundamental contributions, particularly to the processes of problem identification, policy goal and action formulation, and progress monitoring.

7.1.1 Resource and Environmental Data Acquisition

Global monitoring requires that the *entire earth* be observed at *adequate spatial and temporal resolutions* (c.f. Section 6.3.1). Space, or satellite, remote sensing which is characterized by the fast repetition of the earth surface coverage, thus offers a unique

means to meet this requirement. Launched in U.S. in the 70s when concerns with natural resources were raised worldwide, the earth resources satellites Landsats 1, 2 and 3 marked a major breakthrough of using space remote sensing for earth resource survey. Over the past decades, the growing concern about the sustainability of the earth environment has been driving the rapid advancement of the science and technology of remote sensing (NASA 1999). The spatial resolution of satellite images has been improved from 82 meter to 1 meter (van Wyngaarden 1998). The wavelength sensibility has widened from visible, to near infrared and infrared, and to X-ray and radio wavelengths. Accordingly, the observable objects have been extended from terrestrial features, such as topographic forms and land use, to a vast-range of environmental phenomena, such as atmospheric ozone thickness and distribution (Brechenridge et al. 1993, Cracknell and Varotsos 1995, NASA 1996, CIESIN 1995).

Whereas the US still plays a major role in satellite observation, there are now a number of other countries involved, including Brazil, China, Canada, France, India and Japan (Kondratyev et al. 1998). With joint efforts coordinated by the Committee on Earth Observation Satellites (CEOS), a range of large scale environmental monitoring systems are being put into place, including the Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS), and Global Terrestrial Observing System (GTOS), developed in the context of the World Climate Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP).

The end of the last century was marked with the launch of the Earth Observing System (EOS) in the context of the Mission to Planet Earth (MTPE) Programme (more recently called the Earth Science Enterprise) - the major observational and scientific element of the US Global Change Research Program (USGCRP 1999). EOS is the first observing system to offer integrated measurements of the earth's processes. It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, atmosphere and oceans (EOS 1999). These monitoring programs altogether provide full coverage of the vast-ranged phenomena of the earth environment, with temporal

resolutions adequate for global, regional and local assessment of environmental dynamics (Kondratyev et al. 1998).

Broadly, the data acquired through earth observation can be grouped into two categories. One includes those that serve directly for the generation of sustainable development indicators for the purpose of environmental monitoring. Of the indicators proposed by the United Nations, for example, many can be derived from remote sensing imagery directly, including land use change, changes in land condition, vegetation index, land affected by desertification, sustainable use of natural resources in mountain areas, and density of hydrological networks (Langaas 1998). For Canada, about 30 percent of the data required for the indicators of sustainable forest management can be obtained through remote sensing (Goodenough et al., no date). Remote sensing methods can also substantially meet the observation requirement for ecological monitoring of Canada (Environment Canada 1995).

The other category contains the observational data that are needed for the modelling and simulation of spatio-temporal environmental processes in support of sustainability problem identification and policy formulation. Of the ten data sets identified for this purpose by the United Nations, remote sensing plays a major role in acquiring the data sets for infrastructure, land use and land cover, hydrology, climatology, topography, and soils. It can also be used as a complementary approach to the acquisition of demographics, air quality and water quality data (UNEP 1997b).

The role of earth observation in support of sustainability policy-making is substantial. In dealing with climate change, for example, uncertainties associated with climate change predictions are the major impediments to policy commitments. The uncertainties are essentially a result of an inadequate understanding of the role of a number of climate influencing factors, including cloud-cover dynamics, global energy and water cycles, atmosphere-ocean interaction, polar ice cover dynamics, land surface processes and feedback, solar activity impacts, and sources and sinks of greenhouse gases and aerosol, as well as the processes which transform the gases and substance in the atmosphere.

(Kondratyev et al. 1998). A good understanding of these factors and their processes is required to differentiate the climate variability caused by anthropogenic activities from that caused by natural variation. Table 7-1 outlines the range of variables that are needed

Table 7-1: Variables observable by remote sensing and needed for climate change modeling and prediction (according to NASA 1996)

Data status	Themes	Variables
Time series exist; observation needs continued and improved	Atmosphere	<ul style="list-style-type: none"> . solar irradiance . stratospheric aerosols . total ozone and vertical profiles . lower troposphere water vapor . cloud radiative properties and temperature
	Ocean	<ul style="list-style-type: none"> . upper layer surface temperature . sea-level topography and surface fluxes
	Land surface	<ul style="list-style-type: none"> . vegetation cover and properties
	Cryosphere	<ul style="list-style-type: none"> . extent and concentration of sea ice . extent of the continental snow cover
Key missing or inadequately sampled; technology available for observation	Atmosphere	<ul style="list-style-type: none"> . water vapor profiles in upper troposphere and lower stratosphere . tropospheric aerosol properties . evaporation
	Ocean	<ul style="list-style-type: none"> . surface wind stress
	Land surface	<ul style="list-style-type: none"> . surface temperature . evaporation
	Cryosphere	<ul style="list-style-type: none"> . ice sheet topography
Key missing; technology yet to be developed	Atmosphere	<ul style="list-style-type: none"> . precipitation . three-dimensional winds . cloud microphysical properties and 3-D structure
	Ocean	<ul style="list-style-type: none"> . surface salinity . surface heat flux
	Land surface	<ul style="list-style-type: none"> . soil moisture . evaporation . heat flux
	Cryosphere	<ul style="list-style-type: none"> . snow amount or depth . sea ice thickness

for the research, as well as the status of remote sensing in meeting these needs (NASA 1996). These observations will allow a more synthesized and in-depth analysis of causal factors of the observed climate variability and feedback processes that govern the response of the climate system. As such, they will improve various climate prediction

and impact assessment models, and also serve as more reliable baselines for prediction and forecast. The associated uncertainties can thereby be significantly reduced.

In order to meet data requirements for sustainability policy-making, however, remote sensing images need to be complemented with field observations ("ground truth"), for several reasons. First, not all of the environmental phenomena can be observed by means of space and airborne remote sensing, due to such limitations as spatial resolution and radiative properties. Second, regional field experiments are also needed in order to understand the physical processes under study; in situ measurements are necessary to meet the needs. Last but essential, ground truth survey provides reference for the interpretation of remote sensing data as well as the evaluation of remote sensing techniques; it also serve as a reference for the validation of process models (NASA 1996).

A geomatics technology with potential to facilitate field survey is the global positioning system, in particular the differential carrier phase surveys technology (Dana 1999). With a reference station available within 30 kilometres, a remote GPS receiver can be used in field survey to receive a position for any fixed location. By correcting bias errors at the field location with measured bias errors known at the reference station, this technology can position any point on the earth surface, with an accuracy less than 1 centimetre. With the position data available, environmental observations obtained from the field can then be placed in a spatial framework, available for subsequent spatial and/or temporal analysis.

GPS can also directly serve for the acquisition of environmental data. For example, the GPS/MET receiver launched in a satellite in 1995 has been obtaining vertical atmospheric profiles of temperature and moisture across the globe with a high spatial and temporal resolution (NCAR 1996). The positional signals sent by the GPS are affected, or delayed, by changes in density in the atmosphere, which is a function of pressure, temperature and moisture. This "wet delay" can be used to back infer the temperature and amount of water vapor present in a given column of air.

7.1.2 Framework Data Acquisition

Remote sensing imagery must be linked to the *geoid* to establish geographical positions of observations. Field observations also need to be recorded with respect to the *geoid*. The bridge for these linkages is framework data, which sets up a spatial frame with known geographical location and positional accuracy (Goodchild 1996). The provision of framework data is essentially the core of geomatics science.

Geodetic control network lays the bottom layer of the spatial framework, with a positional accuracy of 1 centimetre. Traditionally, the establishment of this network relies on the astronomical observation coupled with accurate timekeeping, but GPS is replacing this role. The second layer of the spatial framework usually consists of fixed monuments, for which differential GPS provides the best means to establish positions. Topographic maps at different spatial scales comprise the upper layers of the spatial framework. Airborne remote sensing images are usually used for deriving small and medium scale topographic maps, while satellite remote sensing imagery is preferable for small scale topographic mapping.

7.2 GIS - The Unique technology for Geospatial Data Integration, Analysis and Communication

The worldwide concern about earth resources and the related issue, population growth, in the late 60's and early 70's also gave rise to a new technology - geographical information systems (GIS). GIS as a technology can loosely be defined as systems of computer hardware, software, and procedures designed for the capture, management, manipulation, analysis, modelling, and display of spatially referenced data. Over the past decades, however, the evolution of this technology has broadened the scope of GIS, and given rise to the new meaning for the acronym of GIS – Geographical Information Science. As a science, GIS now encompasses additionally the theories and methodologies for the processing and analysis of geospatial information. Characterized by its capabilities of handling spatial information, GIS offers a unique tool for dealing with the challenges

involved in support of sustainability policy-making, in particular the integration of geospatial data from different sources, and the subsequent analysis and the visualization of geospatial information. As such, it contributes to the critical policy processes of problem identification and policy formulation.

7.2.1 Data Integration

To enable the integration and analysis of geospatial data, GIS⁸ are equipped with such fundamental functions as spatial data acquisition, manipulation and management. Geospatial data, such as land inventory, Census and remote sensing data, can all be managed and utilized under the same system environment. Through manipulation and conversion, these data can be made compatible in terms of geographical reference, data model, format, projection and scale. A geometrically consistent, integrated spatial database can thus result, ready for subsequent utilization. The recent advancement of spatial data engines in a client-server environment has made the management of large scale spatial databases more efficient and effective (Oracle 1999).

The efforts to develop integrated spatial databases in support of sustainability policy processes are evident (Matthews 1993, Waston and Wadsworth 1996, Walker and Young 1997, Harold and Tony 1998). For example, at the global scale and with a focus on the integration of environmental data, the Global Ecosystems Database Project (GEDP) is devoted to making compatible the global data sets that are needed for global environmental and ecological characterization (Kineman et al. 1996). Also at the global scale but with emphasis on the integration of earth sciences data with socio-economic data, the Consortium for International Earth Science Information Network (CIESIN), as part of the U.S. Mission to Planet Earth program, attempts to provide integrated databases in support of global change research (Miller 1996). The wide scope entails the involvement of a broad range of data communities, from United Nations agencies and regional statistical organizations to social science data archives and data collecting

⁸ GIS refers to Geographical Information Systems throughout this thesis, unless specially referred to Geographical Information Science.

agencies all over the world. GIS provides a fundamental tool for making these data compatible and consistent.

7.2.2 Analysis of Spatial Dynamics

The real power of GIS in support sustainability policy-making, nonetheless, lies in its capacity for geospatial data analysis. The most fundamental, and widely used, analytical function of GIS is overlay. It enables the integration of multiple factors in the analysis of spatial diversity of sustainability issues. Its ability to relate multiple variables within a spatial context makes it an indispensable tool for policy development dealing with spatially-explicit issues, such as sustainable land use and the conservation of biodiversity (Aspinall 1993, Hallett et al. 1996, Walker and Young 1997, UNEP/RIVM/PE 1997). It plays an important role in the broad area of earth science as well, since many modelling and simulation tasks involve multiple variables in a spatial context (Mladenoff et al. 1996, Matthews 1993). The down-scaling of climate change predictions to regional scales, for example, is performed based on an overlay of global predictions with such regional environmental characteristics as topography, soil and vegetation properties (NASA 1996).

In terms of scale effects, GIS provides a unique tool for tackling the complex issue of spatial scales suitable for ecological study, sustainability assessment, policy decision making and implementation. Its capabilities of data conversion, manipulation and visualization allow the analyst to explore the effects of both spatial and temporal scales of social, economic and ecological processes, which could hardly be explored without GIS. DeGloria and Wagenet (1996), for example, use GIS, coupled with a soil process model and a scientific visualization system, to improve understanding of soil processes and the influence of environmental factors on soil quality, at discrete spatial and temporal scales, thereby supporting sustainable land use policy-making. Whereas efforts for the in-depth exploration of spatial scale effects are still limited in the context of sustainable development policy support, the methods developed for exploring the Modifiable Areal

Unit Problem⁹ (MAUP) can be borrowed to advance this area of GIS application (Wrigley et al. 1996, Green and Flowerdew 1996, Openshaw 1996).

Moreover, GIS are increasingly used in the simulation of spatial or spatio-temporal processes for environmental research. They provide tools for data manipulation and visualization, with coupled process models¹⁰, such as hydrological, ecosystem and landscape models, to simulate spatial processes (Moore 1996, Johnston, et al. 1996, Miller 1996). Mladenoff et al. (1996), for example, linked a spatial model of forest landscape disturbance and succession to a GIS system, to simulate changes in landscape structure in response to fire and windthrow disturbance regime combinations, as well as forecast harvest levels and patterns. Unless a friendly user interface is developed on top of the models and GIS, the coupling approach often creates inconvenience for analysts, due to the need for frequent data transfer. An alternative is to develop models within GIS, or vice versa, as exemplified in Maxwell and Costanza (1992), Maidment (1996), Fedra (1996), Lam and Pupp (1996).

7.2.3 Visualization of Spatial Phenomena

Other than spatial data integration and analysis, GIS also provides a unique tool for the communication of sustainability information to policy decision makers as well as the general public. The key functionality for this purpose is spatial information visualization. Visualization facilitates the comprehension of the scientific concepts of environmental sustainability, and the interactions between social, economic and environmental phenomena. As Wilbank (1994) comments, "The growing power of the visual image in human communication in this age of an information revolution is well recognized. . . The creation and diffusion of visual images is displacing the printed word as a triggering mechanism for issue identification, constituency building, and agenda-setting. . . No other form of communication is as powerful among such a wide variety of audiences".

⁹ According to Longley and Batty (1996, cited from Openshaw 1984), the modifiable areal unit problem refers two related issues. One is the 'scale problem', which arises because different results can often be obtained when data from one set of areal units is progressively aggregated into lower and larger units for analysis. Two is the "aggregation or zonation problem", namely that different combinations of a given number of areal units can also yield widely different results.

The electronic atlas is the most straightforward form of using visualization in support of policy decision making. Initiatives, for example, are underway to develop electronic atlases for eight Latin American countries, in order to support sustainable development policy decision making (Taylor et al. 1998). The Population, Environment and Sustainable Development Atlas of China is under development as well, with an aim to present policy makers with an integrated view of sustainable development issues (Liu et al. 1999).

Visualization also serves as an analytical function for the exploration of spatial dynamics. Based on the visualization function of GIS, for instance, Batty (1996) constructed an urban animator to confirm some hypotheses on urban growth. The hypotheses were rejected through the animation, showcasing the effectiveness of visualization as a spatial analytical tool. The role of visualization in the simulation of spatial processes for environmental research and policy scenario assessment is self-evident (Mladenoff et al. 1996, Walker and Young 1997).

7.3 Geomatics Technology for Spatial Data Access and Delivery

The broadness and integrativeness of sustainability issues make a vast quantity of disparate data at different scales a necessity for the processes of policy-making. These data sets reside in different locations, making access to, and delivery of, them a great challenge. The emergence of the Internet technologies offers a great opportunity for geomatics to address this challenge. Initiatives to deliver spatial data using this technology are springing up across the globe (Evangelatos 1998, Masser and Salge 1998, Moeller 1998, Taylor et al. 1998).

With a focus on sustainability research and policy support, the most comprehensive endeavour, among these initiatives, appears to be the Global Change Data and

¹⁰ Models that simulate the real world process of the phenomenon under study.

Information System (GCDIS 1999), the data distribution component of the US Global Change Research Programme. GCDIS is a collection of distributed information systems operated by U.S. government agencies involved in global change research. Through the World Wide Web, it provides a gateway to a wide range of data involving atmospheric science, ecology, oceanography, as well as economics and sociology. The data is available online, with accessibility varying from query, viewing, downloading to purchasing.

The evolution of spatial data distribution initiatives has given birth to a new concept - Spatial Data Infrastructure (SDI). In general, SDI refers to the mechanisms for spatial data sharing and delivery based on the Internet technology, particularly the Web. The Canadian Geospatial Data Infrastructure (CGDI), which is being implemented through the GeoConnection program, for example, represents the government of Canada's initiative to connect and disseminate geospatial data and information, in collaboration with lower levels of government and industry (NRCan 1999a). Similar efforts are being made in U.S., Europe and other countries, in an attempt to put "more control, more information, more decision-making power into the hands of families, communities, and regions" (FGDC 1999, GISED1 1999).

Other than distributing geospatial data, efforts are also observable to enable the visualization of these data through the Web, with corresponding texts attached to explain their thematic contexts. For example, the 6th edition of the National Atlas of Canada was launched on the Web in 1999, with a set of ecosystem-based maps presented in support of policy analysis dealing with ecological sustainability. A more extensive service for the visualization and thematic explanation of geospatial data in relation to sustainable development is found from the Web site of the Consortium for International Earth Science Information Network sponsored primarily by the US government (CIESIN 1999b).

Chapter 8

Challenges and Opportunities of Geomatics in Support of Sustainability Policy-making

Despite the wide-spread application of remote sensing and GIS, tremendous potential remains for geomatics to further serve the processes of sustainability policy-making. This potential can be examined with respect to the issues of geospatial data, and the use of GIS in sustainability problem identification, policy option formulation, and decision making. Also, the characteristics of sustainability policy-making give rise to a series of conceptual issues regarding the technology and application of GIS. To realize this potential and address the concerns raise challenges as well as opportunities.

8.1 The Data Issues

Data is a fundamental element in support of sustainability policy-making, in particular problem identification and policy formulation. While tremendous effort has been made to acquire data, data availability remains a significant issue in sustainability policy decision support. In relation to geomatics, the shortage of data, the accessibility to existing data, and the compatibility of data from different sources comprise the main issues.

8.1.1 Need for More Data

At the global level, tremendous gaps exist in the core data sets identified as necessary for sustainability assessment (UNEP 1997b). For example, for the framework data to which the core data sets of hydrology, topography and infrastructure belong to, much does not exist, is not available because of concerns for national security, or is old (Goodchild 1996). Mapping at 1:100,000 scale or better with 50 meter accuracy existed in paper or digital form for only 59% of the earth's land surface, of which only a fraction is available to environmental applications (Goodchild 1996). The advancement of remote sensing may provide abundant and economical supply of digital elevation data and digital orthophotography, but the identification of cultural features and features invisible from

space will remain costly and labor-intensive. Similar challenges are possible for other core data sets (including demographics, economy, land use and land cover, climatology, soils, air quality and water quality), other global data sets needed but not included in the core sets, as well as regional, national and local data sets that are required for the respective levels of quantitative assessment in support of sustainability policy-making.

8.1.2 Data Accessibility

For the data already acquired, accessibility is a challenge. The efforts to build spatial data infrastructures as well as various data clearinghouses do have improved this situation to some extent. Good accessibility, however, implies multiple data services including data discovery, evaluation, visualization and access. Widely-reached catalogs need to be developed for the discovery of geographically-dispersed data holdings. Metadata descriptions of data sets, following a commonly accepted metadata standard, need to be provided for data evaluation. Visualization tools need to be made available for users to “get a feeling for the data”. To allow for access to, and visualization of, distributed data holdings, commonly agreed geospatial data standards need to be used for data storage, and systems that hold the data should be made interoperable through the network.

Currently, however, the capability of data discovery is still limited, due largely to the lack of a well-developed policy environment that encourages data sharing and application (Taylor 1998). Initiatives for the development of data standards as well as system interoperability are observable, including the development of metadata standards by the US Federal Geographic Data Committee (USGCRP 1999), the Open Geographical Datastore Interface (OGDI) by Global Geomatics (1999), and the GIS interoperability by the Open GIS Consortium. Concerted collaborations, however, are needed in order to achieve the success.

8.1.3 Data Compatibility

Even with all the data made accessible, there still remains the issue of data compatibility for efficient and effective use of the data. A variety of incompatibilities may exist in data sets from different spatial databases. Richardson (1998) characterizes them as follows:

Syntactic incompatibility - each data set may be implemented in a different GIS. This often occurs when an application involves multiple data sources.

Model incompatibility - real world phenomena are represented in spatial databases with different data models, such as the vector or raster model.

Schematic incompatibility - the same real world phenomenon may have different levels of abstraction in different systems, albeit the same data model, and even the same syntax, is used. For a city, for example, a church may be modeled as an object in one database, and a property in another.

Semantic incompatibility - the same real world phenomenon may have different thematic descriptions in different databases; or the same description may refer to different real world phenomena, even with the same syntax, data model and scheme used.

Spatial incompatibility - The same real world entity has different spatial descriptions in different databases. This often results from different scales of generalization.

Temporal incompatibility - Data are captured at different times; the real world changes during these times result in a different thematic and/or spatial description of the same phenomena.

The issue of syntactic incompatibility has received most attention of all these issues, since it directly affects access to different databases through the Internet. The advancement of data interoperability, based on a common spatial data standard in the context of SDI, may well address this problem. All the other issues, however, seem to be neglected in the current SDI efforts to a different degree (Richardson 1998). The reasons are perhaps multifold. First, the current endeavour is focused on spatial data sharing, with the primary objective being the accessibility to data in distributed systems by the Internet users, whereas all the other data compatibility issues only occur when data come into use. Second, the major actors in the current SDI efforts are government agencies and

geomatics sectors, with data captured through various government programs, while all the other compatibility issues arise in the user community. Third, the challenges involved in dealing with all the other heterogeneity issues would be so enormous that, without concerted efforts from both the data supplier and user community, it seems hardly conceivable to set up any achievable objectives.

In addition, there may also be some misconceptions regarding these issues. Model incompatibility, for example, may simply not be considered as an issue, as the spatial data model problem is usually interpreted as the vector versus the raster model problem, and the conversion between them can be made with most proprietary GIS packages. This understanding, however, is mistaken. It is true that, technically, most current GIS have the capability of converting raster data into vector data or vice versa. But in many cases, this conversion is simply not doable, especially in addressing the issues of sustainable development. As Miller (1996) comments, there is a significant gap between socio-economic data collected for social science research and those for research in natural sciences. "The former are collected and intended for use within political systems or are obtained from probability samples of the national population which cannot be disaggregate geographically without doing violence to sampling assumptions or violating privacy and confidentiality restrictions". The latter are acquired mostly in a grid system, with its spatial resolution determined according to the requirement of natural science research. Thus, when socio-economic and physical data need to be merged, conversion is more likely to be performed from the raster to vector format, namely from grids to administrative units. In integrated assessment of environmental sustainability, such merging is typically required, but the analytical units are often grids rather than political units (UNEP/RIVM/PE 1997).

The compatibility of geospatial data, however, is a necessity for any application that involves more than one data set. It is thus conceivable that the effort to make data compatible and integrative is unavoidable before any analysis can be carried out. The effort will be duplicated whenever the same data set is involved. Duplications will

further create incompatible data sets. With the improvement of data accessibility and the subsequent increase in application, the potential of data incompatibility will further grow.

Requirements for well-integrated data sets, in fact, have been raised from the user sustainable development policy community (personal conversations with Ian Marchall (Environment Canada 2000) and David Welch (Parks Canada 1999)). Some activities are observable for meeting these requirements. For example, EcoMap, a set of social, economic and environmental maps integrated into ecosystem frameworks, have been created in the National Atlas of Canada (NRCan 1999c). A more systematic effort is being made at the Environmental Account Branch of Statistics Canada, with the aim of providing well integrated social, economic and environmental data sets for sustainable development policy-making. The scope of the integration, however, is still limited, and concerted endeavours remain a challenge (c.f. Section 9.6 for an in-depth discussion).

8.2 GIS for Sustainability Problem Identification

Whereas problem identification appears to be the sub-process of sustainability policy-making in which GIS are used most frequently, the scope of application is essentially very limited. In most cases, GIS serve only for data manipulation and visualization, minor processes compared to such major processes of modelling and simulation in earth system research. This limitation in application is mainly due to the limitation of GIS technology, in particular GIS data models, spatial analysis and modelling environments, as well as dynamic visualization capabilities.

8.2.1 Data Model

A data model, in a general sense, is an abstraction of the real world which incorporates only those properties thought to be relevant to the application at hand (Goodchild et al. 1996a). In GIS usage, it is often used to refer to the representation and organization of spatial data. Common GIS models are the vector data model, which represents a spatial phenomenon via individual objects, and the raster data model, which discretizes space into regular cells with spatial objects embedded through cell values. The data models

were designed to deal with maps and images, but are found to be substantially lacking in ability to support sustainability problem identification. This inadequacy is multifold.

First, these models deal with spatial phenomena in a static manner, whereas sustainability problems are dynamic. With the vector model, for example, spatial objects are modelled in a concept of layers. The locational data of a layer are stored in the database with topological structures maintained so that spatial relationships can be retrieved. The attribute data of the layer are organized in a relational table indexed to the locational file. Any temporal data are but attributes in the relational table. To deal with temporal change, the usual solution is to represent different time slices as separate layers, and to overlay the relevant layers together to explore changes. Any attempt to trace the change of a spatial object is extremely difficult, due to the lack of mechanisms for temporal information retrieval across the layers (Langran 1992). The same is true for the raster data model. The lack of a spatial-temporal structure inhibits GIS' use in earth system research.

Second, socio-economic and environmental dynamics often involve multiple dimensions, whereas these data models mostly deal with two dimensions, or two and a half dimensions. The vertical measurement of spatial objects is counted only for a half, since it is only an attribute in a vector spatial database. Its topology, which is often required as well in the modelling of environmental dynamics, is exclusively unavailable (Goodchild et al. 1996a). There is no true three-dimensional raster structure either in common GIS. For the purpose of data storage, multiple layers of two-dimensional raster can be used to simulate a three dimensional raster, but access to data so stored is clumsy at best and analyses can only be performed by tools custom written for the purpose (Frysinger et al. 1996). The weakness of GIS in dealing with multi-dimensional objects impedes its application in sustainability research. In the use of GIS in atmospheric- hydrographic-, and ecologic-coupled climate-system modelling, for example, Lee et al. (1996) have to convert temperature data from three dimensions into two dimensions for interpolation.

Third, spatial objects are represented in precise measurements, whereas sustainability problem identification requires that the inherent uncertainty associated with measurements be made explicit. Spatial data, like any other data, are inaccurate by their nature. Errors initially occur during the process of data acquisition, due either to the instruments, operators, or the procedures of acquisition. Thematic contents are erroneous as well, subject to the sampling procedures or thematic classifications (Goodchild 1993). These errors are compounded with the errors generated in the process of data manipulation, such as generalization (Haining and Arbia 1993). These compounded errors are propagated into the processes of spatial analysis and modelling, in which they are further compounded with the errors caused by model parameters and mathematical operations (Aspinall and Pearson 1996).

The issue of data quality and error propagation in GIS has received extensive treatment in recent years. A variety of models have been developed to describe and trace errors occurring in these processes (Thapa and Bossler 1992, Goodchild et al. 1992, Goodchild 1993). These endeavours, however, remain as mainly academic exercises, due largely to the lack of appropriate mechanisms in GIS that allow the quality data to be incorporated into the analysis. The problem, therefore, is again rooted in the data model of GIS.

8.2.2 Quantitative Modelling Environment

The development of quantitative models is a fundamental task for sustainability problem identification, particularly earth system simulation and impact assessment. Tools for model building are therefore an integral part for any computing environment intended to support sustainability research. The current GIS, however, centre on maps rather than model building. Such packages as SPANS do provide modelling capabilities, but the model parameters must be estimated beforehand. Also, only simple models can be supported by such systems, due to the interpretive nature of the programming language provided. Some statistical modelling tools, such as regression and Kriging, are available in such GIS as ArcInfo. But the functionality is very limited. For regression modelling, for example, ArcInfo supports only conventional regressions – an approach that has been demonstrated unsuitable for spatial data modelling (Anselin 1988, Griffith 1996). No

functionality is provided for spatial regression (spatial econometrics) – the techniques developed particularly for the empirical modelling of spatial data in recent decades (Anselin 1988). It is the lack of modelling capabilities pertinent for the modelling of spatial as well as spatio-temporal processes that disables the current GIS to serve as a prescriptive tool (Batty and Longley 1996, Nyerges 1993). As a result, the capacity of GIS is largely confined in the context of sustainability research.

8.2.3 Scientific Visualization

Whereas visualization is the strength of GIS, the visual capacity of GIS is essentially limited in terms of the need for sustainability problem identification. Unlike the general applications of GIS that emphasize the visual display of two-dimensional distributions of static spatial objects, sustainability problem identification requires scientific visualization, which emphasizes dynamic visualization, exploratory data analysis, and proactive visualization (Buttenfield 1996, Wanger et al. 1996, Timmins and Hunsaker 1996, Knapp et al. 1996).

Sustainability deals with processes, either social, economic, environmental or their interactions. As most processes occur over space, GIS are a fundamental tool for their visualization. Processes, however, also occur through time exclusively. The visual display of time-series information is therefore essential. With the combination of spatial and temporal information, three kinds of display are thus needed: a static map to show the spatial distribution of a phenomenon at a particular time point; a time-series graph to show the temporal dynamics of a phenomenon on a particular spatial location during a period of time; and animations to show the spatio-temporal dynamics over space during a period of time. The current GIS, however, can only support well the first type of display. The second type is disabled unless time-series data of a particular location are stored in one file. While there is a growing body of research focusing on dynamic mapping (Buttenfield 1996, DiBiase et al. 1992), animation is rarely readily available in any current proprietary GIS.

Visualization in the context of sustainability research is often aimed at exploring data rather than visual display *per se*. Visualization techniques that aid in exploratory data analysis are therefore of particular use. Examples of such analyses include the search for variables from a database that is spatially correlated to the variable being examined; the identification of spatial abnormalities from a spatial distribution; the visual display of multi-dimensional data in a geographical space, and the search for patterns over the space (Knapp et al. 1996, Wanger et al. 1996). While three- to four-dimensional visualization in a geographical space is supported in many proprietary GIS, specialized scientific visualization packages tend to provide superior multi-dimensional effects (Wanger et al. 1996). Various statistical graphics, which portray objects in a 1-to-n-dimensional variable space in different forms (such as XGobi), are useful tools for data exploration as well. These functions are being enhanced in the current GIS. Compared to statistical or scientific visualization packages, however, GIS remain weak in this aspect.

To facilitate data exploration, Battenfield (1996) contends that GIS should enable proactive involvement of users into the visualization process, as opposed to interactive involvement. Unlike interactive visualization that provides capabilities to take actions anticipated by system designers, proactive visualization “refers to taking actions before it is mandated by a system request”. With such a system, the user should be able to manipulate images to enable system commands or database queries, in order to steer modelling and computation. Visualization thus serves not only as a visual tool, but also as an easy-to-use command tool that links screen visuals to actual numbers that reside in databases.

Furthermore, scientists engaged in sustainability research are mostly not experts in GIS and visualization. They should not be required to design maps, as in the current GIS (Wanger et al. 1996). Instead, they only should have to identify what is to be viewed via browsing the data, and then let the system to figure out how to do the visualization. Given the wide-ranged functionalities for scientific visualization, the visualization component of a GIS should be equipped with such level of intelligence that scientists without much knowledge on visualization can use the tool efficiently and effectively.

8.3 Geomatics in Support of Policy Action Formulation

GIS have found significant use in urban and regional planning (Worrall 1991, Newkirk 1991, Wellar 1992a, Birkin et al. 1996 p149). Applications of GIS in support of urban or regional policy-making are observable as well, albeit at a limited capacity and with a limited number (Boalt and Bernow 1991, Wellar 1992b, Watson and Wadsworth 1996). Watson and Wadsworth, for example, developed a decision support system to model rural land use and its change due to environmental and agricultural policy. In the context of sustainable development, such applications are few but observable. The integrated assessment model IMAGE2, for example, employs GIS in support of its land use component (UNEP/RIVM/PE, 1997). Walker and Young (1997) demonstrate an example of using integrated economic and ecological information from a State-wide Resource Information and Accounting System for policy scenario assessment. These applications all share one commonality – dealing with spatially-explicit issues, with a clear bias on land use.

Some sustainability policy issues, however, appear aspatial at the first glance, but spatial in essence. Greenhouse gas reductions issues, for example, may appear aspatial, since global warming as a result of greenhouse gas emissions occurs at the global scale. When reaching the stage of policy option formulation, however, they are spatial, as policy impacts and mitigation measures will vary considerably with space. Geomatics, therefore, has potential to contribute to the policy option formulation processes that address such seemingly aspatial issues. This potential, however, remains to be realized to a large extent, as evidenced in the process of formulating greenhouse gas reduction policies in both Canada and U.S. (NRCan 1996a, DOE 1996). The realization of this potential can be analysed with respect to quantitative assessment, consultation, and policy decision making.

8.3.1 GIS for Quantitative Assessment of Policy Options

The formulation of sustainability policy alternatives is performed mainly at the national level. Policy scenario assessment plays an important role in this process. GIS could potentially contribute to this process in at least two aspects: enabling the incorporation of spatial diversity and spatial interactions in policy scenario assessment and impact analysis; and integrating social, economic and environmental data to allow for the consideration of all these factors in policy-making. To realize this potential, some obstacles must be addressed, in addition to the data accessibility and compatibility issues, which were addressed in Section 8.1.

First, the need for considering spatial diversity in sustainability policy-making must be sufficiently recognized by the policy community. This recognition is insufficient in current practice. This is partially due to the convention of national policy analysis, which addresses policy issues at a high level of geographical aggregation (national or provincial). The information used is hence at the high levels as well. This convention is naturally continued as the policy analysts undertake the assessment of sustainability policy scenarios and impacts. In Canada, for example, policy assessments are usually performed down to the provincial level, with an assumption that the areas within each province are homogeneous for the issues of concern.

Second, disciplinary gaps are also an impediment to the application of GIS in policy scenario assessment. The general understanding of GIS as a descriptive tool suggests that GIS are not the right tool for the support of the prescriptive process of policy scenario assessment (Batty and Longley 1996). This suggestion is valid in the sense that the current GIS do lack a modelling environment for prescriptive tool development. However, this modelling environment can be created in different ways, for example, by coupling an appropriate modelling package with a GIS. Spatial statistics as techniques for spatial econometric modelling are found to be an appropriate approach, which can take spatial diversity as well as dependency into account, thereby producing policy scenarios that are not only spatially explicit, but also capable of representing spatially-dependent human-environmental relations. The limited awareness of spatial statistics,

even within the GIS community, however, hinders the realization of this potential. Partnerships between the policy and geomatics community need to be established to bridge the disciplinary gaps.

Third, policy alternative formulation is often performed under a tight time-line. A timely response to the needs of policy assessment is a key to policy analysts (Walker and Young 1997). Conceivably, the development of GIS based policy assessment tools would take some time and effort, especially at the initial stage of application. The lack of this specialization among policy analysts makes this development more difficult. This issue reinforces the need for partnership development between the policy and geomatics community, not only during the implementation of spatially-based analytical tools, but also in the initiation of the undertaking. Moreover, the spatially-based tool should be made easy-to-use for policy makers.

Furthermore, some limitations of GIS technology inhibit its use in policy option formulation as well. Other than the lack of modelling environment, the current GIS are also weak in spatial analysis capabilities (Batty and Longley 1996). Spatial heterogeneity¹¹ analysis, for example, is of particular value to policy scenario assessment with consideration to spatial diversity. It can reveal the varied effects of human-environmental interactions over space, and different impacts of policy options on different places. Such analysis has been developed in the academic community (Getis and Ord 1996, Anselin 1988), but rarely included in the proprietary GIS.

8.3.2 Access to Sustainability Information in the Consultation Process

The current development of spatial data infrastructure is improving the accessibility to spatial data. For individuals who are involved in the consultation process of policy option formulation, however, of particular interest to them would be information rather than data. Herein, information is defined as

¹¹ Spatial heterogeneity, in terms of spatial statistics, refers to varying relationships between variables in different geographical areas. Refer to 12.2.1 for more details.

Information = data + conceptual model + thematic context

where data refers to the materials that are collected or derived for representing or simulating individual aspects of the real world, conceptual model to the mental abstraction that makes the data understandable, and thematic context to the explanation of the data in relation to the sustainability theme being addressed. For the issue of climate change, for example, a forecast of temperature in the form of a grid across the globe is data. This data becomes information when it is overlapped with reference data layers and understandably visualized in the form of map, with thematic information associated to present the issue context.

To facilitate this consultation process, a centralized information service should be provided based on the Internet technology, with a comprehensive view of sustainability information made accessible to all the policy participants as well as the general public. The comprehensiveness is threefold: from theory to practice; from the problem to policy scenarios; and covering a complete spectrum of sustainability issues. Access to such comprehensive sustainability information would enable the users to gain a big picture of sustainable development issues, as well as the detailed information of their special concern. It would also help them to understand the policy solutions to the problems of concern. Public participation in the policy process could therefore be improved.

8.3.3 Geomatics in Support of Policy Decision Making

Given the facts that decision analysis and conflict resolution are the two primary elements of sustainability policy decision making (c.f. Section 6.3), and that space is an important aspect in dealing with sustainability issues (c.f. Section 6.2), a question naturally arises: can geomatics technology that deals specially with spatial information offer any support to ease the process of decision analysis and conflict resolution? Whereas GIS have been widely used in support of real world decision making in the areas of natural resources management and business application (Birkin et al. 1996, Christopher 1998, Jack 1998, Joseph 1998), the application of this technology in sustainability policy decision making is rarely observed. The supporting information for

the decision making process is usually provided by policy analysts, in the form of policy documents. The direct use of information technology is limited primarily to the improvement of presentation effects.

Several shortcomings can be identified in this practice. First, access to factual information is limited to that present in the policy documents. Any information at spatial, sectorial, or demographic aggregations different from those presented in the documents is not readily accessible. Second, policy scenario assessment is confined to policy documents as well. Any demands for assessing policy variants, such as a different magnitude of tax increase, have to be forwarded to policy analysts. As only very limited numbers of policy scenarios can be assessed compared to the possibilities, this restriction reduces the flexibility of policy negotiation. Third, it is difficult for policy decision makers to express different views and interests, since the lack of group-based visual interactive facility limits the use of human's visual capacity in assistance of concept understanding, especially in relation to the spatial dimension. Furthermore, decision-makers likely apply differing criteria for option evaluation. The lack of facilities to evaluate policy alternatives according to each individual's criteria discourages the use of information in decision making. These combined shortcomings affect conflict resolution and consensus building.

The recent advancements in Internet technologies have offered opportunities to overcome some of the shortcomings. With a relatively straightforward effort, the Internet-based sustainability information service, as proposed in the previous section, can be used to improve policy decision-makers' access to geospatially-based factual information as well as policy scenarios. A more advanced endeavour could be made to adapt the Internet-based business intelligence technologies to the spatial domain, to equip policy decision makers with an "intelligent" decision analysis tool, based on geospatial information/knowledge (c.f. Section 8.4).

In addition, the recent research activities in Collaborative Spatial Decision Support Systems (CSDSS) have also shown a potential to facilitate conflict resolution as well as

decision analysis in sustainable development policy negotiations (Armstrong 1994, Bennett 1996, Densham et al. 1996, Jankowski et al. 1997). CSDSS are intended to “enable groups of people to work together by providing a set of generic tools that handle many of the tasks that are required of group enterprises: exchange of textual, numerical and graphical information; and group evaluation, consensus building and voting” (Densham et al. 1996). This research initiative also attempts to characterize the processes of collaborative spatial decision making in various subject domains including the environment.

Bennett (1996) proposes an advanced conceptual CSDSS model for ecosystem management, based on Minski’s “society of mind” model. Minski models human mind as a set of competing and collaborating agents each of which is designed to complete a specific task or objective. Following this concept, decision-makers can be conceptualized as a society of complex interacting agents who work together toward a common goal. System functionalities dealing with data, models, evaluation and coordination are modelled as automated agents, which serve the decision-maker agents whenever needed. Based on this model, a CSDSS would be comprised of a ring of distributed workstations, one for each decision making agency, and a central one for performing common tasks (automated agents) including decision analysis and a forum for debate and compromise. A more advanced system could even include a “broker-agent” (an expert) in the central workstation, which analyzes potential solutions and recommend options, data and models to agencies that may be able to make use of them (Bennett 1996).

With such a system, a decision making process could begin when decision-makers each submit to the central workstation a set of criteria for alternative evaluation. The criteria that are contained in all decision-makers’ submission would be composed into a common set of criteria. Alternatives already proposed would be evaluated, based on both the common criteria and each individual’s criteria. New alternatives could be proposed by decision-makers, or generated by the system, with scenarios forecast and visualized. Debate could be facilitated through inter-agency communication facilities such as

whiteboard and message posting. This whole process would iterate, with criteria to be modified by decision-makers, in order to seek compromised alternatives and build consensus. As such, decision analysis becomes dynamic, and communication among negotiating parties is improved. Decision-makers could collaborate on the refinement of model assumptions, evaluation criteria, as well as policy options, thereby encouraging the development of mutual-agreeable compromise.

8.4 Conceptual Issues of GIS in Support of Sustainability Policy-making

GIS is not merely a technology. It represents a set of social practices and institutions embedded within a particular discourse. In the application of GIS in support of sustainability policy-making, a series of conceptual issues are worth attention. In particular, what are the epistemologies of GIS as well as the worldviews underpinning them? What is the political economy of geographical information production and access? Are there any alternative approaches to GIS development that may improve GIS production, use and access in support of sustainability policy processes?

GIS deal with the modelling of the real world in a digital form. While this process has been characterized in different ways, a two-step transformation can well describe this process: the transformation of the real world (W) to the mental model (M), and then to the digital model (D) (Huang 1994). The WM transformation is the basic procedure of geomatics and geographic research. Whereas different approaches are used in the understanding of the complexity of the geographic world, positivism remains to be the dominant approach in the context of GIS production. The world is perceived as objective existence, and the purpose of the research is to obtain the facts about this existence (knowledge) through scientific methods.

With the mental model developed, the MD process then follows to transform it into a form appropriate for GIS representation. As different individuals could have different mental models about the real world, the first task of this transformation is to unify

multiple mental models (termed external models in database design), to form a “global” view of the real world (termed conceptual models) (van der Schans 1990). The conceptual models are then tailored to conform the rules of implementing a specific GIS, resulting in logical models – a set of polygons, lines and points with attributes associated. The logical models are implemented in GIS, finally transformed into digital models.

In terms of reasoning, two main epistemological positions dominate GIS: visualization-based empiricism and analysis-based rationalism (Sui 1996). Sui explains that the former sees knowledge as the product of sensor perception, resulting from a kind of mapping or reflection of external objects, through our sensory organs, possibly aided by different observation instruments, to our brain/mind. The latter sees knowledge as the production of rational reflection through the integration of GIS with spatial analysis and modelling. Ontologically, GIS is thus embedded in the positivistic dualism and rationalism, as well as its conceptualization of space and time.

In the context of sustainable development, this set of epistemology and ontology raises a series of questions. First, different perspectives on sustainability issues likely lead to different understanding of the subject matter, namely different mental models. These understandings may be in conflict with each other but “true” to different groups. How can GIS incorporate such “multiple realities” into a GIS representation, rather than “unifying” them (van der Schans 1990)? Second, other than the scientific approach, there are different ways of knowing the world, including gestalt, iconographic, and allegorical methods (NCGIA 1996). Local knowledge with regard to sustainability is of particular value (Weiner et al. 1996). How can a GIS incorporate diverse types of knowledge in its representation? Third, information is of key importance to sustainable development. GIS, especially its analytical functions, however, are difficult to access without specialized training. How can GIS be made accessible to non-expert users including ordinary citizens as well as school students, in order to improve the public’s participation in the sustainability policy process? More fundamentally, how can GIS go beyond the scientific materialist worldview, adapting to the emerging worldview of nature as an organism (c.f. Section 4.1)?

These questions raise fundamental challenges to the technology of GIS. Similar issues have been raised in the research of GIS-society relations, a recent initiative of NCGIA (Schroeder 1996). The concept of alternative GIS, GIS/2, is proposed, in an attempt to address these issues. Schmitt and Brassel (1996) propose the development of "open systems which provide opportunities for new types of questions and responses and facilitate creativity", moving philosophically from "systems for control" to "systems for prospective exploration". A related initiative is also launched by NCGIA to develop formal models of common-sense geographic world, which may enable the representation and analysis of geospatial information associated with non-standard knowledge such as local knowledge (Mark et al. 1995).

Even with all these technological challenges well addressed, there still remains a series of conceptual issues on GIS' application to sustainability policy support. In particular, how is existing geographic information of the environment socially embedded and what political processes help to reproduce hegemonic representations of nature (NCGIA 1996)? How can GIS be made equally accessible to different social groups for their empowerment in the sustainability policy process? How can the knowledge, needs, desires and hopes of marginalized groups be adequately represented as input to this policy process? What policy impacts might arise for GIS containing conflicting information associated with the inclusion of multiple realities? Furthermore, GIS has represented a top-down approach to governance. If resource throughput is planned from the top (c.f. Section 4.3), GIS would be particularly useful to disseminate the relevant geospatial information. The challenge is how to create such a participatory GIS that can fuse the information from the top with the input from the bottom, so as to facilitate the iterative process of sustainable development policy.

Chapter 9

Towards An Integrated Solution to Supporting National Policy Action Formulation: An On-line National Policy Atlas for Sustainable Development

The challenges of geomatics in support of policy action formulation, as analysed in Section 8.3, can essentially be summarized into two gaps. The first gap lies between the policy community and the geospatial information production community, which impedes policy makers' access to relevant geospatial data and their recognition of the importance of spatial diversity in sustainable development policy-making. The second gap exists between the policy community and the geomatics technology community, which becomes an obstacle to the effective use of the power of geospatial information/knowledge in the policy-making process, even if the policy makers have gained access to the relevant geospatial data. Obviously, it is a tremendous challenge to bridge both the gaps with any single effort. A comprehensive analysis of the challenge and the recent technology advancements, however, has revealed that it is possible to develop an integrated solution to closing these gaps to a significant extent. That is, the development of an On-line National Policy Atlas (ONPA) aimed at supporting sustainable development policy action formulation, or generally sustainable development policy-making. This chapter proposes the ONPA concept. A brief description is provided with respect to the purposes and conceptual model for such a policy atlas, the current status of the knowledge and technology for its implementation, and the major research and development activities required to create the atlas.

9.1 Purposes of the On-line National Policy Atlas (ONPA)

The on-line national policy atlas is aimed at providing relevant policy makers with two major services: an information repository containing geospatial information related to sustainable development; and a spatially-based policy analysis tool in support of policy-making. Herein, policy-making refers only to national policy action formulation (*c.f.* Section 5.4). Policy makers refer to policy developers (including policy analysts, policy

designers and stakeholder representatives involved in the policy-making process), and policy decision makers. Policy supportive knowledge is loosely defined as rules and statements that are derived either from geospatial data or from predictive models, and that are useful, or potentially useful, for policy-making.

With regard to the policy user categories and specific policy supportive tasks, the policy atlas is aimed at providing information and knowledge support

- for policy developers, with the processes of
 - visualization of spatial distributions of relevant variables,
 - geospatial data integration and reporting across different maps and different spatial frameworks,
 - spatially related analysis aimed at discovering policy supportive knowledge,
 - policy scenario projection and impact assessments, and
 - policy document generation and option review;
- for policy decision makers, with the processes of
 - individual decision making, and
 - group policy decision making.

At the same time, the atlas would contribute to participatory democracy and research related to sustainable development. In particular, it would

- provide the general public with comprehensive and detailed information and knowledge regarding sustainability issues, thereby increasing the public awareness of sustainable development policy issues;
- allow the users to better understand, and/or further explore, policy scenarios, thereby facilitating their participation in public consultations dealing with these policy issues;
- provide relevant researchers with a “big picture” (c.f. Section 4.5) for their research, thereby facilitating the orientation of research activities towards “wisdom” (c.f. Section 4.5); and

- enable the researchers to disseminate and access available geospatial data related to their research.

In terms of analytical capacity, the proposed atlas is intended to answer such general policy questions as:

- Where are the problem areas?
- What are likely the reasons for the problem?
- What if no additional policy intervention is made?
- What if some policy actions are taken? And
- Where and who may be most or least affected by the policies?

9.2 A Conceptual Model of the ONPA

In general, a national atlas is a collection of maps that present a national overview of a country's social, economic and physical environment markups. Over the past decades, the national atlas has evolved from the paper atlas, to the electronic atlas (Siekierska and Taylor 1991), and most recently to the on-line atlas, namely the Internet-based atlas available through the Web. The National Atlas of Canada, the 6th edition, is an example of the on-line atlas (NRCan 1999c). With an atlas engine and a spatially-consistent geospatial database residing in the server, an on-line Atlas generally allows the Web user to visualize the spatial patterns of selected themes in the form of maps, with texts, photos and charts available upon retrieval. It may also support map based queries and map browsing, allowing the user to obtain more detailed information when zooming in. Some atlases (e.g. the National Atlas of Canada) may even provide map customization functions, enabling the user to compose maps according to their needs.

The proposed on-line policy atlas is based on this general atlas construct, but expanded substantially in both the content and functionality.

9.2.1 Content Model

With respect to content, the policy atlas would be structured according to sustainable development issues. Different approaches have been used to categorize the issues (e.g. from the perspectives of social, economic and natural resources (UN 1997b)), the approach to the ONPA issue construction is primarily ecocentric, with the life support system, natural resources, human resources, natural biophysical communities, and human communities all being parts of sustainability concern. Figure 9-1 presents a framework for the content of the ONPA.

Figure 9-1: A content framework for the national policy atlas for sustainable development

Within each policy issue, a comprehensive suite of maps would be presented to address the issue in a systematic manner. While the structure of the map suite may differ slightly among different issues, a general structure, as shown in Figure 9-2, would be used as a basis. Available, related geospatial data would be made accessible via the issue maps, to allow for efficient dissemination of, and access to, geospatial data sets.

Figure 9-2: Policy issue map model of the on-line national policy atlas

Attempts are made to develop the ONPA content model in a holistic manner (c.f. Section 4.5), with special attention given to the decomposition of the environmental sustainability issue, and representation of issue content. The clearness of the model and the level of interlinkages that can be represented among the issues, however, constitute a contradiction. The proposed model is neat in terms of its horizontal decomposition among policy issues and vertical decomposition into the issue map structure. However, it remains to be explored as to how the complex interrelatedness as a major characteristic of sustainable development policy issues can be taken into consideration in content development, and clearly visualized in the issue map environment.

9.2.2 Functionality Model

The conceptual model of the ONPA functionality is presented in Figure 9-3. The diagonal arrow shows the expansion of the Atlas' capability towards transforming geospatial data into on-line policy supportive knowledge. Along the arrow are the functionalities to be added to the atlas in order to achieve this transformation. The projections of the functionalities to the X and Y axes are the developments required with respect to the knowledge and technology dimensions (c.f. Sections 9.4 and 9.5 for some details).

Figure 9-3

Specifically, the left bottom corner refers to the general on-line atlas capability. It would serve as the basis of the ONPA model. Its main functionalities include

- Geospatial data visualization;
- Map browsing;
- Single map based query;
- Map design;
- Retrieval of related resources when needed.

The first expansion from this basis would be the addition of a policy issue mapping capability, which is aimed at presenting policy issue oriented maps in a comprehensive and expressive manner. With this capability, the policy atlas would

- Allow the visualization of geospatial information structured according to the sustainable development issue framework and the issue map model ;
- Make use of other multi-media visualization techniques, such as statistical visualizations, photos, texts, and animations, in the main Atlas interface, with hyperlinks to be made among these elements, to complement the map visualization methods; and
- Enable the user to access other geospatial data sets related to the topics being addressed, through the issue maps interface.

Based on this expansion would be the development of the cross-map, cross-framework analysis capability. With this capability, the user would be able to

- obtain geospatial information across different maps and different spatial frameworks; and
- drill down for information when needed.

In the case of climate change policy – transportation energy policy issues, for example, tables could be generated to report alternative fuel refilling infrastructure, or road

network density, based on the framework of Census Divisions first. Details of the retrieved attributes, such as alternative fuel refilling infrastructure, could be further obtained by simply clicking the relevant table item.

The next expansion aims to equip the atlas with a variety of spatial data mining capabilities, to enable the policy users to discover the spatially-based knowledge needed for policy design. Examples of such mining functions include the discoveries of

- Spatial associations;
- Spatial clusters;
- Regional difference;
- Correlations;
- Spatial autocorrelations;
- Spatial heterogeneity; and
- Multivariate clusters.

Methods for spatial analysis, statistical analysis and spatial statistical analysis, therefore, would comprise the core of the spatial data mining capabilities. But spatial data mining would go beyond all these analytical techniques in two main aspects:

- It would be equipped with the mechanisms for efficiently searching through the relevant spatial database for solution-finding; and
- It would attempt to make sense of the analytical results, namely to transform the results into a form of knowledge.

For example, to find out what are the possible factors contributing to the high vehicle fuel intensity in a given province, in the context of climate change – transportation energy policy design, spatial data mining would offer the option to automatically “mine” the database, and tell what factors are significantly correlated to the factor being examined, rather than merely letting the user to choose the variables for correlation analysis and

presenting correlation coefficients as the results. In addition, the data mining capability would also include

- appropriate knowledge visualization capability, to allow for an effective machine-human communication of policy supportive knowledge.

The further expansion of the atlas functionality is intended to incorporate the predictive and policy scenario assessment capability into the Atlas. As such, the Atlas would be able to answer such questions as:

- What if no policy action is taken?
- What would be the effect if a certain policy action is taken?
- Why would be the effect? and
- Who and where would receive the largest/least impact?

In the case of transportation energy policy design, for example, a policy measure of gasoline tax increase may be proposed. Assessments could be performed with regard to the effect of this tax on fuel efficiency improvement (therefore for greenhouse gas emissions reductions from vehicle use), and the possible reasons for this effect. The impacts of such a tax on social and economic dimensions could be further examined, in terms of demographic profiles (such as population age groups, occupations, and incomes), and regional differences. As for spatial data mining, the policy scenario assessment capability would also include

- knowledge visualization capabilities, which may be expanded from the mined knowledge visualization to meet the needs for visualizing policy scenarios and potential impacts.

Finally, the atlas would be equipped with knowledge access capability, to make the knowledge discovered through data mining and policy scenario assessments accessible for later use. This capability would be characterized by

- the ability to save discovered knowledge into a policy supportive knowledge base;
- the ability to support query for the policy supportive knowledge; and
- the ability to explain how this knowledge is derived when asked.

In the process of transportation energy policy decision making, for example, the policy analyst may save the knowledge discovered for fuel intensity policy-making into a knowledge base. The decision-makers may query whether a gasoline tax increase would create a significant effect for greenhouse gas reductions in transportation. If the answer is no, they may make further queries for the reasons.

As can be observed, the content and functionality models of the ONPA are actually interrelated: the issue map contents are the substances for policy supportive knowledge explorations, as well as the results of the explorations. An appropriate strategy is therefore needed for the development of issue map contents, so that the topics of a policy issue are well addressed, with related geospatial information/data available for further explorations.

9.3 Rationale

The conceptual model of the national policy atlas is proposed based on the needs to bridge the gaps between the policy community and the geospatial information production and technology communities, in terms of its role in facilitating geomatics application in sustainable development policy-making. Particularly, it is intended to enable the inquiry of the general policy questions as listed in Section 9.1.

The on-line national atlas, as currently practiced, provides a generalized, centralized, spatially-consistent geospatial information service, with a considerable outreach capacity. By complementing contents with sustainable development policy issue maps, the atlas could serve as a pertinent media for bridging the gap between the policy community and the geospatial information production community. With the built-in geospatial data

visualization capabilities accessible through the Internet or Intranet, such an atlas could also allow the policy users to explore problem areas, and look at the spatial patterns of the factors under examination.

Such an atlas, however, can hardly answer policy questions beyond problem areas. Even for the question of problem areas, it is limited in dealing with complex problems, since it depends on the human visual capacity which is constrained when spatial patterns become too complex. These limitations, together with the existing gap between the policy community and the geomatics technology community, would confine the role of the geospatial information in the policy-making process to merely providing geospatial information references.

This role, however, could be significantly advanced by taking advantage of the recent advancements in spatial predictive modelling (Anselin 1988, Cressie 1993, Griffith 1996) and business intelligence technologies (Han et al. 1997, Information Discovery 1999), as well as the existing geomatics technologies and statistical techniques. The key is to identify a suite of functionalities needed for the generation of the answers to the general policy questions, and make it accessible to policy makers. The best media to deliver this analytical service, without doubt, would be through the atlas environment, in which the relevant geospatial data are available. The functionality of the national policy atlas is developed based on this consideration.

More specifically, to identify complex problem areas and explore the reasons behind the problems, multiple data layers or multiple maps often need to be overlapped at the data level (rather than merely graphically), to allow for queries across different maps and different spatial frameworks. For example, if one region is found significantly high in average vehicle fuel intensity, policy analysts may want to explore whether this region is significant high in other areas of energy intensity as well, such as commercial and residential buildings. They may then want to identify the factors that are correlated to the high energy intensities. Overlay (often termed spatial join) is therefore needed to put together the maps concerned, thereby allowing for across-map queries. Overlay across

different spatial framework needs to be supported as well, since the maps involved in the analysis may use different spatial frameworks (e.g. Census Divisions for the vehicle fuel intensity map and line networks for the transportation road map). Moreover, the analysts may start an exploration at a high level of spatial aggregation (e.g. Census Division), and then go into a more detailed level (e.g. Census Subdivision), after a problem area is identified. Within the proposed functionality model of the national policy atlas, the cross-map, cross-framework reporting capability, which is based on the On-Line Analytical Processing (OLAP) technology available for business intelligence (Eddy 1999, Han et al. 1997), is intended to serve these purposes.

For identifying the possible reasons for a problem, a mere spatial overlay is insufficient. Correlation analysis is basic in supporting the identification. Spatial correlation may improve the inference of correlation by considering spatial effects¹². Statistics, spatial analysis, as well as the recent advancement in spatial statistical analysis, provide a range of analytical functions for this purpose. For example, spatial association analysis can be used for identifying spatial relationships (such as “contained” or “within a certain distance”). Spatial clustering analysis helps reveal spatial patterns (such as high or low value concentration). Multivariate classification is capable of identifying spatial objects/areas with similar characteristics in a concerned variable space. And spatial heterogeneity analysis can be used to identify changing relationships between variables across space. In the case of climate change – transportation fuel efficiency policy design, for example, the analyst may want to identify what are the major reasons for the high average fuel intensity of an identified area (correlation). If several factors are identified, they may further want to explore which areas have the common characteristics (multivariate classification), and whether there exists significant difference in the causal relationships across space (spatial heterogeneity analysis). The capability of knowledge discovery in the functionality model is aimed at supporting these analyses. By adapting a data mining methodology - another advancement in business intelligence, these analytical functions would be made user-friendly.

¹² Spatial effects refer to spatial dependence and spatial heterogeneity. Refer to 12.2.1 for more details.

To answer what-if questions, however, spatially-based predictive models¹³ are indispensable. Such models should be developed off-line, and linked to the atlas to allow for on-line interactive simulations of policy scenarios. The policy scenario assessment capability, as proposed in the functionality model, deals with this on-line simulation and the associated impacts analysis. The development of this functionality is relatively expensive, since different policy issues would usually require different models. However, this functionality, as evident in several policy scenario studies (Davis et al. 1993, EEA 1999a), is of key importance to policy-making. The recent advancement in spatial (temporal) statistical modelling provides an opportunity for the efficient development of spatially-based predictive models to serve this purpose. Models developed using other modelling approaches may be applicable as well, depending on their capability of supporting policy scenario assessments, and the suitability of spatial resolutions for the national policy context. Among these approaches are process-based modelling, which usually simulates the temporal process of a spatial phenomenon and then scales up to some levels of spatial aggregation (Maxwell and Costanza 1994); discrete choice modelling (Train 1986), which models individual choice decisions based on user survey samples; conventional econometric modelling (c.f. Section 10.5 for more details) based on time-series data using regression models; and systems dynamic modelling with an emphasis on the modelling of feedback and delays (Meadows et al. 1992).

It should be noted, however, that the process-based approach, which is the primary approach to earth system modelling, is more suitable for modelling natural phenomena, because of its focus on micro-level processes. Models aimed at supporting policy-making usually deal with human activities, since policies can usually only influence human activities. In the case of climate change, for example, process-based earth system models, along with many other scientific evidences, have supported the critical inference on climate warming. To address climate warming, policy makers need greenhouse gas emission models, which incorporate socio-economic variables, to assess policy measures.

¹³ Spatially-based predictive models herein refer to all the models that produce prediction or forecast at a level of spatial aggregation appropriate for the national policy atlas context.

For the development of such models, the other three modelling approaches are generally more appropriate. Econometric modelling and system dynamic modelling, however, are very expensive in supporting policy assessment at low level of spatial aggregation (c.f. Section 10.5 for details). Discrete choice modelling has a sound theoretical basis in terms of modelling personal choice, but it is problematic in terms of its mathematic basis (c.f. Section 10.5 for details). In the national policy atlas context, therefore, spatial statistic modelling (also termed spatial econometric modelling or spatial regression modelling) is expected to be the principal approach to model development in support of policy scenario assessments.

The visualization of policy supportive knowledge could be very simple, if the knowledge is in the form of rules or statements. However, some visualization methods may improve the understanding of knowledge. For example, a causal relationship chain would be much more communicative than a paragraph of text, for the understanding of the variable relationships. Also, links between the knowledge to the supportive geospatial information, presented in the form of maps or statistical graphs, may enhance the communication of knowledge as well. Therefore, methods may be explored to enable effective knowledge visualization.

For policy decision-makers, however, the atlas functions of interest would primarily be the provision of policy supportive knowledge, explanation of the knowledge when asked, and visualization of related geospatial information when needed. They may also perform some explorations, usually to a limited extent. For example, they may assess the policy effect based on a different magnitude of tax increase, or look into the factors related to high fuel intensity, based on areas of special concern. Selected or newly discovered knowledge, when saved in a knowledge base, may further be accessed for use in the following group discussions on policy decisions. The knowledge access capability of the proposed functionality model is aimed to enable such knowledge-related operations. As such, geospatial information and knowledge would be made available to policy decision-makers in a flexible and efficient manner. The knowledge access capability, in essence,

is of great use for policy developers as well, in the processes of policy analysis, design, consultation and documentation.

Figure 9-4 illustrates the role of the proposed policy atlas in bringing both geospatial information and relevant geomatics technologies to the policy makers. The data of the atlas will reside in the national atlas data warehouse, while all the proposed technological functionalities will be implemented within the policy decision support engine. As such, geospatial information and technology, namely geomatics, would play a substantial role in sustainable development policy-making.

9.4 Current Status of Knowledge and Technology for Implementing ONPA

A survey on the availability of the primary knowledge and technologies that are required for the implementation of the ONPA functionality model has been conducted, based on the Web as well as other accessible information. The results are briefly summarized in Table 9-1. It should be noted that, this survey is by no mean exhaustive. The primarily Web-based survey also implies that further advancements may have been made in practice, because of the normal delay of Web presentations. This survey, however, has focused on recent geomatics research initiatives in the US, Canada as well as Europe, with an emphasis on GIS. Therefore, the result is believed to be representative, and have represented the leading edge developments, with at most one year of delay compared to other literature.

9.5 R&D Required for ONPA Implementation

Based on the available knowledge and technologies, applied R & D are needed for both knowledge and technology development, in order to implement the policy atlas concept. Table 9-2 outlines the major efforts required with respect to each ONPA functionality.

Figure 9-4: The national policy atlas in bridging the gaps between the policy community and the geospatial information production and geomatics communities

**Table 9-1: Availability of knowledge and technology for the ONPA implementation
(created by the author)**

Functionality	Knowledge	Technology
Policy issue mapping	<ul style="list-style-type: none"> - Available 	<ul style="list-style-type: none"> - Main technology available - Technology for linking statistical graphs and maps to be investigated
Cross-framework analysis	<ul style="list-style-type: none"> - Core knowledge available - A user requirement analysis underway 	<ul style="list-style-type: none"> - Oracle solution available - Spatial OLAP solution proposed (Eddy 1999) - Technology for non-spatial data available (OLAP) - OLAP being adapted to GIS in two GEOIDE research projects¹⁴ (Bilards et al. 1999, Bedard et al. 1999)
Knowledge discovery	<ul style="list-style-type: none"> - Analytical methods mostly available - Some knowledge available for spatial data mining - Is a major component in the current GIS research agenda in both Canada and US - Some knowledge visualization methods available 	<ul style="list-style-type: none"> - On-line data mining technology for non-spatial data available (OLAM) - A preliminary off-line spatial data mining prototype available; research proposed to move the prototype on-line (Han et al. 1997) - OLAM being adapted to GIS in a GEO research project (Bedard et al. 1999)
Policy scenario assessment	<ul style="list-style-type: none"> - Some spatial predictive models available (Climate change -transportation) - More spatial predictive models being developed or planned - Applications recently found for spatio-temporal predictive modelling, which can extend the scope of spatial statistics in developing policy supportive models 	<ul style="list-style-type: none"> - Technology available for spatial predictive modelling - Technology available for on-line model implementation
Knowledge access	<ul style="list-style-type: none"> - Concepts available in the business intelligence domain for strategic decision support (non-spatial) 	<ul style="list-style-type: none"> - Technology recently available in the business intelligence domain for strategic decision support (non-spatial domain) - termed the 21 century technology

Table 9-2: R & D needs for the ONPA implementation (created by the author)

Functionality	Knowledge	Technology
Policy issue mapping	<ul style="list-style-type: none"> - Identify sustainable development policy issues appropriate for inclusion in the atlas - Develop contents of policy issue maps 	<ul style="list-style-type: none"> - Develop a policy issue mapping interface - Implement multimedia visualization capability
Cross-framework analysis	<ul style="list-style-type: none"> - Design a multi-dimensional geospatial database (cubes) for the policy atlas, based on the non-spatial multi-dimensional database concept 	<ul style="list-style-type: none"> - Choose an appropriate solution for map overlay (Oracle solution or proposed SOLAP (Eddy 1999)) - implement multi-dimensional database functionality, according to OLAP technology
Knowledge discovery	<ul style="list-style-type: none"> - Conceptualize spatial policy supportive knowledge - Identify analytical methods for discovering policy supportive knowledge - Design spatial data mining methods based on the identified analytical methods - Identify or further develop methods for spatial knowledge visualization 	<ul style="list-style-type: none"> - implement the identified analytical methods by means of spatial data mining - Implement knowledge visualization methods if unavailable in the atlas
Policy scenario assessment	<ul style="list-style-type: none"> - Explore the feasibility of the spatial predictive modelling approach to model development in support of policy scenario assessment - Identify existing predictive models for the atlas - If feasible, develop spatial (temporal) predictive models appropriate for the atlas - Develop concepts and methodologies for spatially-based policy impact analysis 	<ul style="list-style-type: none"> - Implement spatial predictive models in the atlas - Implement spatial impact analysis capabilities, based on spatial data mining functionalities.
Knowledge access	<ul style="list-style-type: none"> - Adapt the knowledge access concept from the business intelligence domain to the spatial, policy context - Design a knowledge base model - Design a knowledge query builder - Design a knowledge explanation mechanism 	<ul style="list-style-type: none"> - Implement a knowledge base using on a commercial database (e.g. Oracle) - Implement a knowledge query builder - Implement knowledge explanation functionality - Implement knowledge management functions if necessary

¹⁴ GEOIDE (GEOmatics for Informed DEcisions) is a major Canadian geomatics research initiative (1999 - 2003) (<http://www.geoide.ulaval.ca/Public/an/accueil/index.html>). It involves over 20 universities, with partners from Canadian governments and the geomatics industry.

As shown in this table, the implementation of a fully-functioned national policy atlas as proposed would entail tremendous effort. An appropriate implementation strategy is needed in order to achieve success. Three approaches are of crucial importance for this strategy: a partnership approach, a phase-based approach, and a case-based approach. Partnerships should be established among atlas developers, policy makers, and university researchers for research activities, with private industry further added for technology development. A phase-based approach should be used for the expansion of the atlas functionality, both across functionality modules, and within functionality modules.

A case-based approach should be used as well, since the policy issue orientation of the atlas also implies that the atlas would be successful only when it becomes useful in support of policy-making in a particular policy case. This case would serve as a basis for the development of the atlas functionalities with respect to the needs for knowledge discovery, policy scenario assessments and knowledge access. It could also be used to demonstrate the capability of the atlas in support of policy-making, thereby facilitating the further development of the atlas, in the same policy area or in other policy areas. Given the fact that the analytical needs for different policy issues may vary to some extent, caution should be used in the selection of the policy case and the identification of policy supportive functions, so that the functionalities developed based on one case would have large reusability in other cases.

Conclusions of Part II

The policy process of sustainable development can be characterized into six iterative sub-processes: sustainability problem identification, agenda setting, policy goal formulation, policy action formulation, implementation, and evaluation. In this part as well as throughout this thesis, policy-making refers to the former four sub-processes in its broad term, and only to policy action formulation in its narrow sense.

In relation to space, sustainable development policy-making, both in its broad and narrow sense, share several characteristics, including the broad and integrative nature of the policy issues, the complex spatial dynamics involved in the policy issues, and the importance of participatory democracy in the policy-making process. These characteristics present special challenges for policy-making aimed at sustainable development. Dealing with these challenges commands the use of a vast range of environmental and socio-economic data, as well as the associated technologies and methodologies.

Geomatics has been used in addressing these needs, most prominently in the process of problem identification. In particular, satellite remote sensing, complemented with GPS, has been serving as a principal approach to earth resource observation and environmental monitoring. GIS are used subsequently, primarily for integrating remotely sensed imagery with socio-economic data, overlaying multiple variables for integrated modelling and assessment, and visualizing the spatial distributions of the phenomena under study. Geomatics technologies have also been extended to the Internet, improving the accessibility to geospatial data required in support of the sustainability policy process. Efforts to use geospatial information in support of policy formulation are observable, but remain very few and confined to spatially-explicit policy issues, typically land use.

Substantial challenges are present for geomatics to further serve the process of sustainability policy-making. With regard to data, the challenges exist in the acquisition of a vast variety of data to meet the needs for quantitative assessments of sustainability

issues and policies, the improvement of data accessibility, and the integration of the diverse data into a common spatial framework. To play a more essential role in sustainability research, GIS need to be improved in several aspects: to incorporate temporal components, high dimensions, and uncertainty measures into their data models; to equip the system with a modelling environment to allow for the development of empirical and spatio-temporal process models; and to enhance their capability for scientific visualization. These improvements would meanwhile enhance GIS' role in the process of policy goal and action formulation.

Additional challenges need to be addressed in order to apply geospatial information in the formulation of sustainability policy actions. Among these are the improved recognition of the need for considering spatial diversity in sustainability policy-making by policy makers, the development of partnerships to bridge the disciplinary gaps between the policy and geomatics community, and the development of an easy-to-use, spatially-based analytical tool in support of policy analysis and scenario assessment. By developing a spatially-based sustainability information service, with functionalities ranging from factual information, to policy scenarios, and to advanced cooperative spatial decision support environments, geomatics could also make more significant contributions to the processes of public consultation and policy decision making.

In addition, the conceptual basis of the current GIS, namely the modernist ontology and epistemology, is faced with fundamental challenges from the emerging theory of environmental sustainability (c.f. Sections 4.1 and 4.5). In the long term, fundamental changes are entailed in the technology as well as applications, in order to address the special needs of sustainability policy-making, including the representation of multiple spatial realities, the incorporation of local knowledge, and the fusion of the top-down and bottom-up information for improved participatory policy-making.

Faced with this range of challenges, this chapter has focused on the conceptual development of an integrated solution to addressing the challenges of applying geomatics to the process of policy action formulation, namely an On-line National Policy Atlas

in Operation Census database, which was merged with fuel consumption ratings and vehicle size class information by the Transportation Energy Use Division of the Energy Sector. They represent the market share of major 1991 model-year new LDV classes, including subcompacts, compacts, midsize cars, small vans and small utility trucks. The second set (Maps 6-10) presents the forecast of market share for 2010 for the same vehicle classes. The changes in the market share for these classes from 1991 to 2010 are presented in the third set (Maps 11-15). The last set (Maps 16-18) includes average new LDV fuel intensity maps for 1991 (historical), 2010 (business-as-usual forecast), and the likely changes from 1991 to 2010.

In relation to the areas of policy interest, the spatial patterns are obvious, as exemplified by the selected major vehicle classes. For the Windsor-Quebec Corridor, the market share of subcompact, compact and midsize cars were particularly high in 1991, while the small utility share was low. The market share of small van shows a clear spatial pattern: the more south-west, the higher market share. Assuming no additional policy intervention, over the forecasting period, the Corridor would see significant, but average compared to other regions, reductions of subcompact market share in most areas. Changes in the market share of compact and midsize cars would be minor, with some areas increasing and some decreasing. The market share of small vans would increase significantly. The most significant growth, however, would take place in small utility vehicle sales. Consequently, in 2010, the market share of subcompacts in the Corridor would become average for Ontario, but still keep high for Quebec. The compact market share would be high overall, and among the highest in Quebec. The market share of midsize cars and small van would be high as well, especially in the south-west. Owing to their low bases, the market share of small utility vehicles, despite of large increasing rate, would remain low to average, except for the Greater Toronto Metropolitan area which would be among the areas to have the highest small utility share. Thus, in terms of average new LDV fuel intensity, the Corridor had low fuel intensity in 1991. There would be low to average improvements in the intensity in the forecasting period, assuming no additional policy intervention. As a result, this area would have average to low fuel intensity in 2010, with its Quebec section remaining the lowest in Canada.

From the geomatics technology perspective, this proposal contributes to the research of spatial policy decision support systems. It also represents a substantial extension of the conventional national atlas concept, and opens up a new research direction for making the national atlas analytical, predictive, and supporting knowledge generation and access, thereby making it an integrated solution to policy decision support.

Three endeavours are of critical importance for the implementation of this policy atlas: the exploration of a feasible approach to spatially-based modelling in support of policy scenario assessment; the identification and development of a suite of spatially-based policy analysis and scenario assessment functions; and the successful adaptation of the emerging business intelligence technologies, including On-Line Analytical Processing (OLAP), data mining and knowledge access, to the spatial, policy domain. Currently, few activities are observed in the first two areas, and some preliminary research activities exist for the third challenge. The research and development required to implement this concept are therefore tremendous. However, the existing knowledge and technologies on spatial analysis, statistical analysis, spatial statistical analysis and knowledge based systems, provide a good basis for the undertaking of this R&D initiative. The keys to the success are a partnership approach that ensures the users' requirements to be addressed by the atlas, and the phase-based and case-based approaches that make this large R&D initiative manageable and deliverable.

Part III

A Spatial Statistics Approach to Predictive Modelling Supporting Climate Change Policy Assessment: The Case of New Light Duty Vehicle Sales Mix and Average Fuel Intensity

Introduction to Part III

As concluded in Part II, three major research topics need to be successfully addressed in order to implement the proposed concept of an online national policy atlas for sustainable development. Specifically, they are the exploration of a feasible approach to spatially-based modelling in support of policy scenario assessment; the identification and development of a suite of policy analysis and impacts analysis functions in support of related policy inquiries; and the adaptation of the business intelligence technologies to the spatial, policy context, to make all the analytical functions, as well as the knowledge generated from these analyses, easy to access.

Part III presents a case study that addresses the first topic, namely the exploration of the feasibility of the spatial statistics approach to developing models in support of policy-making. The policy issue chosen for this study is climate change – the most prominent issue of environmental sustainability in the current decade. In particular, it deals with the policy issues of greenhouse gas reductions in the transportation sector, with a focus on the development of new Light Duty Vehicles (LDV) sales mix models at a low level of spatial aggregation, in support of policy-making aimed at improving vehicle fuel efficiency. Assuming no policy intervention, a forecast of new LDV sales mix and average fuel intensity is performed, in an attempt to provide a spatially-disaggregated outlook, and to explore the feasibility of forecasting based on such spatially-based models. With assumptions of gasoline tax increases, a forecast is further performed to demonstrate the capability of such models in support of policy scenario testing.

The presentation of the case study is structured as follows. Chapter 10 lays out the context of the study in terms of both policy and modelling. Chapter 11 identifies the objectives of the case study. The implementation of the case study is addressed in Chapters 12-14, which describe the conceptual framework for the study, the definitions and processing of variables and data, and the methodologies for model building, business-as-usual forecasting and policy scenario projection. The outcomes of the study are presented in Chapters 15-17, including the new LDV sales models developed, the business-as-usual forecast of new LDV sales mix and average fuel intensity, and the policy scenario projection assuming gasoline tax increases. The end of part III summarizes the characteristics of the models developed and the major findings on new LDV sales mix and average fuel intensity in Canada, and draw conclusions regarding the general research questions of the case study.

Chapter 10

Context of the Case Study

10.1 Canada's Efforts on Climate Change

To address climate change, two main options exist: mitigation, to control and reduce greenhouse gas emissions; and adaptation, to take conscious decisions to cope with climate change. Canada has been part of a concerted international effort to address these issues.

With respect to mitigation, the key is in energy use. As a modern industrial nation with extreme climates, vast distances involved, and a great dependence on energy-intensive natural resource developments, Canada depends heavily on energy. As a result, energy use accounted for 89% of Canada's greenhouse gas emissions in 1995. According to the mainstream approach to sustainable development (c.f. Section 3.2), the contributions of energy to Canadian society, economy and greenhouse gas emissions implies that mitigative responses to the challenges of climate change should take the social, economic, and environmental interests all into account.

Under this principle, Natural Resources Canada, in partnership with other Canadian governments, the private sector, and other stakeholders, has developed a comprehensive Efficiency and Alternative Energy (EAE) Program since 1991. Currently managed under the Office of Energy Efficiency (OEE), this program encompassed more than 40 initiatives (NRCan 1999d). Among them are the information programs to advise energy users about energy efficiency opportunities; voluntary programs through which major energy users commit to set energy efficiency targets as well as action plans; regulations to eliminate the less energy-efficient products from the marketplace; fiscal incentives for energy efficiency in commercial buildings and for heating and cooling from renewable energy sources; new energy performance labelling programs for houses and motor vehicles; and alternative transportation fuel programs to foster the widespread use of

alternative energy sources. A series of R&D programs are also in place to foster the research, development and use of renewable energy sources and the related technologies.

At the same time, initiatives have been taken in the forestry and agriculture sectors, which are the major sources for the remaining 11% of Canada's greenhouse gas emissions. The objectives are to reduce greenhouse gas emissions from these sectors and, meanwhile, to increase the capacity of these sectors as greenhouse gas sinks.

In the field of climate change adaptation, the Canada Country Study, a preliminary study conducted in partnership by over 55 scientists and experts from Canadian governments, industry, academia and non-government organisations, represents Canada's first, concerted effort in assessing the social, biological and economic impacts of climate change and potential adaptive responses for Canada (Environment Canada 1997). It consists of regional studies, sectoral analyses, and studies addressing cross-cutting issues such as landscapes, costing, and domestic trade and commerce. In addition to providing a preliminary scientific basis for policy-making, this study also contributes to the IPCC (International Panel on Climate Change) climate change impact assessments, at both the global and regional levels.

To advance the knowledge in support of climate change policy-making, a variety of other scientific initiatives are also underway in Canada. The areas of focus are on the detection and prediction of climate change; the estimations of greenhouse gas emissions from anthropogenic sources; and research on oceans' role in the carbon cycle and the link between forest and climate change (GC 1999).

10.2 Dealing with the Kyoto Challenge

While sinks and adaptations are important issues, the current international effort in addressing climate change is centred on greenhouse gas reductions. According to NRCan's projection (NCCP 1999), Canada's current effort in mitigating greenhouse gas emissions, like many other industrialized countries, will be offset by continued

population and economic growth. To ensure the effectiveness of greenhouse gas mitigation, the Kyoto Protocol, as a result of the Third Conference of Parties (COPS) to the United Nations Framework Convention on Climate Change, held in Kyoto, Japan in November 1997, established renewed international goals for greenhouse gas reductions, for the first decade of the new millennium (UN 1997a).

Under this legally binding Protocol, industrialized countries must reduce their collective emissions of greenhouse gases by 5.2% by the period 2008 to 2012. Over the same time period, Canada's reduction target is 6% below 1990 levels. Based on the current projections of emission growth, meeting Canada's emission reduction goal, as shown in Figure 10-1, could equate to about a 26% reduction of greenhouse gas emissions by 2010 (NCCP 1999). This target presents Canada with a tremendous challenge.

Figure 10-1: Canada's greenhouse gas reduction target (from NCCP 1999)

Faced with this challenge, the Government of Canada, in partnership with provincial and municipal governments, industries, environmental groups and individuals, is engaged in the development of a national implementation strategy, building on the programs already

in place. This strategy, according to the principle of sustainable development, is required to be flexible and cost-effective, to allow Canada to achieve the emission reduction target while maintaining a vibrant economy, and to ensure that no region, province or sector of the economy is asked to bear more than its fair share of the effort (Goodale 1998).

Two processes receive special emphasis in developing this implementation strategy: public consultation and model-based analysis. Public consultation attempts to engage a wide variety of Canadians in the policy-making process, including a broad group stakeholders, environmental groups, other interest groups and academia. Model-based analysis, on the other hand, enables policy makers, as well as all the people involved in the policy-making process, to envision the future based on different policy scenarios.

10.3 The Transportation Sector

To facilitate the policy-making process, greenhouse gas emissions are decomposed into sectors and reduction strategies are developed within each sector. Figure 10-2 shows a way of decomposition that is used in the projection of Canada's greenhouse gas

Figure 10-2: Canada's greenhouse gas emission projection by sector (NCCP 1999)

emissions. As can be seen from this diagram, emissions will grow from 1990 to 2020 for all the sectors except the residential sector. Transportation, which includes road, rail air and water transportation, is the largest greenhouse gas contributor (accounting for 27% of Canada's total CO₂ equivalent emissions), with a significant rate of growth in the decades to come.

The transportation sector, however, is found to be the most challenging area of policy development aimed at greenhouse gas reductions. The current efforts are centred on road transportation, which accounts for over 70% of transportation energy use (NCCP 1999 p22). Targets for average vehicle fuel consumption have been in effect in Canada since 1978 for cars, and since 1990 for light duty trucks. Over the past few years, a number of information programs have been put into place to support the transportation sector's transformation toward energy efficiency. Examples include the AutoSmart Student Driving Kit to help driver instructors deliver training in fuel-efficient driving techniques, the FleetSmart Program to help fleet operators to find opportunities to reduce fuel costs and GHG emissions through improved energy efficiency, and the new EnerGuide Fuel Consumption Label for Vehicles Program to allow vehicle buyers to select a fuel-efficient model. Efforts to promote the use of alternative transportation fuels are mainly directed at fleet operators in both the public and private sectors.

In the area of science and technology, the Canada's Transportation Energy Technologies Program is supporting the development of competitive, energy-efficient and environmentally responsible technologies for gaseous, alcohol and biodiesel fuels, and for such advanced transportation systems as electric and fuel-cell vehicles. At the same time, effort is made to foster the development of advanced vehicle components, including advanced energy storage systems, hybrid vehicles, advanced materials and advanced power systems. The developments of zero-emission hydro-powered fuel-cell buses by Ballard Power Systems of Vancouver, and advanced electrolyzers (to produce hydrogen from clean renewable energy sources) by Electrolyzer Corporation, highlight Canada's transportation R&D achievements towards greenhouse gas reductions. A joint use of these technologies will result in a zero-emission fuel cycle in transportation.

Many of the benefits gained from these programs, however, have been offset by the trend since 1984 toward heavier and more powerful vehicles, and the recent shift from cars to light trucks (sport utility vehicles and minivans). As a result, average vehicle fuel efficiency improvement has remained modest, namely 2% total improvement between 1984 and 1994. Over the 2000-2020 period, NRCan's Energy Outlook suggests that, for Light Duty Vehicle (LDV), fuel efficiency is expected to improve at a rate of 0.5%, due to technological improvements that are cost effective at current Canadian fuel prices (NRCan 1997, NCCP 1999). On the other hand, the total stock of light duty trucks is expected to rise dramatically relative to cars. While the update of the Outlook (NCCP 1999) suggests that the LDV travel demand should be decreasing slightly, the net result is that, without additional policy interventions, total LDV fuel consumption and greenhouse gas emissions are expected to increase by about 11% between 2000 and 2010, and by an additional 16% between 2010 and 2020 (NRCan 1999). The total emissions from transportation are projected to exceed 1990 levels by 34% in 2010 and close to 60% in 2020 (NRCan 1999).

10.4 Recent Studies on Transportation Policy Measures

Faced with the challenge for transportation sector, the Canadian Transportation Issue Table, one of the Issue Tables responsible for the development of the National Implementation Strategy with respect to specific sectors (c.f. Section 5.4), has been engaged in the investigations into policy options aimed at meeting the Canada's greenhouse gas reduction target. The effort is centred on road vehicles, with a focus on new vehicles, especially new Light Duty Vehicles (LDV). Studies have been conducted to evaluate the potential and cost for reducing new LDV GHG emissions, through the improvement of conventional vehicle fuel efficiency technologies (by Sierra Research, 1999), and the use of alternative fuels along with alternative vehicles (by Levelton Engineering, 1999). A range of policy measures for greenhouse gas reductions have also been assessed in terms of their cost effectiveness by EEA (1999a) and HLB (1999).

With respect to new LDV, Sierra's study analyzes the potential and cost of over thirty technologies that are available for improving the fuel efficiency of conventional LDV. It concludes that, while substantial improvement can be achieved with available technologies, CO₂ emissions cannot be significantly reduced below the 1990 baseline before the cost exceeds the economic benefit to motorists. Even with all available technologies, CO₂ emissions are expected to be 8.2% above the 1990 baseline and 15.1% above the Kyoto target (Sierra Research 1999 p154).

Levelton's study, on the other hand, evaluates fourteen specific potential and future fuels for LDV. The fuels are paired to appropriate current and alternative vehicle technologies, leading to nineteen fuel/vehicle combinations, with greenhouse gas emissions projected on a gram-per-mile basis for each combination. The study concludes that electric¹⁵ and fuel cell vehicles could yield the largest emission reductions, but with the highest cost. The most cost-effective choices are diesel fuel with conventional and hybrid vehicle technologies, followed by hybrid gasoline/electric vehicles, CNG (compressed natural gas) and LPG (principally propane). Among the ethanol and methanol fuels, E85 produced using ethanol from cellulose achieves the highest cost-benefit ratio.

Building on these two studies, EEA (1999a) presents a comprehensive assessment of policy measures for improving the uptake of fuel and technology options. In particular, it assesses the effect of each measure on technology uptake, in terms of the supply of, and demand for, vehicle efficiency and alternative fuels. It then tracks the resulting impacts of the technological changes through to the characteristics of new vehicles, vehicle sales, stocks, travel distance, fuel choice, fuel use and, finally, greenhouse gas emissions. Vehicles are first separated into sub-sectors including cars, light-duty trucks and heavy-duty trucks. Within each sub-sector, vehicles are further characterized according to vehicle engine technologies and fuels. For LDV, vehicle sales are broken down to 14 size classes.

¹⁵ According to Sierra (1999 p181), the estimate of electric vehicle emissions in the Levelton's study does not account for the inefficiency associated with generating electricity from the combustion of fossil fuels.

The fuel efficiency model FEM, part of the National Energy Modelling System (NEMS) of U.S. Department of Energy (DOE 1996), is used to estimate technology penetration in each size class of LDV (including nearly 100 discrete technologies), as well as the resulting average fuel efficiency of each class. It is also used to project LDV market share by size class. For alternative fuel vehicles, the Alternative Fuel Module (AFM), also part of the NEM, is used to estimate the technology uptake as results of changes in such vehicle attributes as price. Based on these estimations, the accounting model CHAMPAGNE (EEA 1999b) is used to track vehicle sales and fuel efficiency by class and model year, vehicle travel and scrappage by class and vintage, total fleet size and total vehicle miles travelled by vehicle class, and total fuel consumption and GHG emission by fuel type and vehicle class. A baseline forecast is produced consistent with NRCan's macro level energy outlook (NRCan 1997).

With reference to the baseline forecast, the level of GHG reductions and the associated cost are assessed for several policy measures, including new vehicle efficiency (GHG reduction) targets; high efficiency/alternative fuel vehicle fleet purchase initiatives; vehicle purchase incentive programs; research, development and demonstration support; ethanol blending incentives; fuel quality requirements; regional/local alternative fuel market development programs; and heavy duty truck initiatives. The study suggests that for a given level of GHG reduction, fuel-efficiency focused measures tend to be more cost-effective than alternative fuel focused measures, due mainly to the high cost of alternative vehicles. The target of a total of 25% LDV fuel efficiency improvement by 2010 yields the highest cost-benefit ratio of all the measures assessed.

Also aimed at improving fuel efficiency, the HLB's study assesses a vehicle feebate policy for Canada. The study uses a full market single pivot-point feebate scheme, in which the vehicle with the median emission level is identified as the pivot point and given zero fee or rebate. The fees and rebates for each of the 95 LDV subclasses are calculated based on revenue neutrality, with a maximum fee of \$4000 and a maximum rebate of \$1450. The dynamic effects of the feebate scheme (such as income and travel effects), are taken into account in the model, to adjust the fleet size and the total mileage

travelled. GHG emissions are calculated according to total vehicle stock, subclass market share, travels, and fuel efficiencies. The analysis concludes that, compared to the measure of the 25% fuel efficiency improvement target, such a feebate scheme yields a little less emission reductions and incurs similar cost.

Two issues deserve special attention for all these cost-effective assessments. One is concerned with the issue of externality. The overall framework of assessments in these studies is based on a conventional economics approach, which measures the feasibility of a policy in terms of its cost-benefit ratio. The environmental impacts (i.e. environmental externalities) of vehicle ownership and use are not taken into account in the assessment processes, due mainly to the lack of appropriate accounting methodologies, and the resources available to conduct the assessments. For example, Levelton's study suggests that diesel fuel in combination with conventional and hybrid vehicle technologies yields the best cost-effective ratio, but diesel fuel is found to be harmful to human health (HEI 1999), which is not taken into consideration in the cost-benefit equation. This exclusion should be borne in mind in using the outcomes of assessments.

The second issue deals with the rebound effect. It seems that a stringent fuel efficiency target aimed at a total of 25% LDV fuel efficiency improvement by 2010 could reduce LDV GHG emissions to the targeted level (21% of the business-as-usual case). A combined feebate scheme could make further emission reductions in the LDV sector. However, all the measures aimed at fuel efficiency improvement could generate rebound effects. That is, lowered fuel consumption and, consequently, lowered fuel cost, could stimulate consumers' interest in driving, thereby increasing the distance travelled per vehicle, as well as the total distance travelled. As a result, the fuel savings that are intended to be achieved through fuel efficiency improvement may be balanced off to some degree.

10.5 The Rationale of A Spatial Statistics Approach to New LDV Sales Mix Modelling

Whereas a range of policy options have been assessed in these studies, and such options as a total of 25% fuel efficiency improvement by 2010 appear to be promising, a review by the Transportation Table, in collaboration with the Municipalities Table and the Technologies Table, suggests that further studies are needed for making immediate decisions to address new LDV emission reductions. New initiatives have been embarked on since then to develop Canadian-based, better new LDV sales models, including sales mix, and based on the new models, to perform more detailed policy assessments aimed at LDV fuel efficiency improvements (TEUD 1999). The identification of an appropriate modelling approach is a leading topic of these initiatives.

As suggested by the previous studies, LDV fuel efficiency improvements based on conventional vehicles would play a major role in achieving LDV emission reductions in the coming decade, although such alternative fuel technologies as ethanol, electric and fuel cell vehicles offer a great emission reduction potential in the long term. These improvements can be achieved through either a command or a fiscal approach. A command approach, such as a more stringent CAFC standard for vehicle manufacturing, could directly enforce the penetration of new fuel efficiency technologies into the market. A fiscal approach, such as a vehicle feebate scheme and fuel price increase, on the other hand, is market-oriented, with an aim to steer consumers' vehicle choice decisions towards more efficient vehicles. The resultant shift in vehicle sales mix in favour of more efficient vehicles could in turn effect the market penetration of new fuel efficient technologies.

For a market-oriented policy, success depends primarily on consumers' response to the policy. A detailed analysis of the factors that affect consumers' vehicle choice decisions is therefore of considerable importance in the development of such a policy. Conceivably, vehicle choice is related to a variety of factors. Among others, any cost associated with vehicle purchase and operations, such as vehicle price, fuel price and

vehicle insurance cost, would certainly be important factors. Demographic factors, such as population age, occupation, income and household size, may also play an important role in the choice decisions. In addition, geographical (or spatial) factors may be considered as well: road conditions, cultures, and rural/city driving, to list a few. Demographic profiles, in essence, also have a root in geography or space. Models that represent well the relationships between these factors and the consumers' vehicle choice decisions would provide a good tool for assessing the effects of market-oriented policies. Such models would also provide clues for the analysis of the impacts of policy measures on different regions and population groups.

In principle, discrete choice modelling, which is aimed at modelling users' personal choice decisions, is an appropriate approach to the development of such models. This approach, however, is not feasible in the current case. One reason is that it requires the use of user survey samples, which are unavailable in Canada for confidentiality reason¹⁶. More fundamentally, its theoretical basis is questionable. Like all conventional regression models, it assumes that all sample observations be independent from each other, and that the modelling error be homogenous across the observations (Train 1986). For a user survey sample, however, these assumptions are very likely violated. For example, users tend to be spatially dependent in vehicle choices, namely users who are geographically closer to each other tend to use similar vehicle choice criteria, and end up with similar vehicle choice decisions, than users who are farther away from each other. Also, the relationships modelled likely vary across space; therefore, the modelling error may be significantly heterogeneous across the observations (or space) as well. The violations of model assumptions, consequently, reduce the reliability of model specifications, and in turn, the reliability of forecast produced based on the models. This problem, as a common problem in regression analysis for model building, has been seriously examined in the areas of regional science and geography in recent decades (Anselin 1989, Haining 1990). Tackling of this problem has led to the emergence of a

¹⁶ While the National Passenger Vehicle Use Survey (NaPvus) could be a good source, the survey data is allowed to be aggregated only to the provincial or national level for any uses, due to the confidentiality commitment.

new branch of statistics – spatial statistics, particularly spatial econometrics (Anselin 1988, Haining 1990). To date, a wealth of techniques has been made available to deal with the spatial effects in linear regression analysis. For non-linear regression modelling, including discrete choice modelling, the demand for a spatially-based approach is evident, but significant progress is yet to be achieved due to the technical sophistication involved in seeking the solution (CISISS, 1999).

An alternative approach to the model development is the standard econometric approach, which models the relationships between vehicle market share (an aggregate representation of vehicle choice decisions) and the contributing factors, based on aggregate, time-series data. Both the Canada's Inter-Fuel Substitution Model¹⁷ (IFSD) (NRCan 1996a) and the Transportation Energy Demand Model¹⁸ (TEDM) (NRCan 1996b) have been developed based on this approach. Light duty vehicles in these models, however, are distinguished only between large and small categories, with mere income and fuel price used as predictor variables in the LDV market share models. The same approach is used for the models of new LDV market share embodied in the Fuel Economy Model (FEM) (the one used in the study by EEA (1999)). While more disaggregate in LDV classes (14 size classes), the FEM LDV market share models also use only income and fuel price as predictor variables. Any improvement of these econometric models to meet the current needs for policy development is also found to be very difficult, due to the limited availability of the relevant time-series data.

In the model used for vehicle feebates analysis by HLB (1999), a series of elasticities of vehicle substitution, generated according to literature and expert opinions, are used for estimating vehicle sales mix shift. No socio-economic and geographical factors are quantitatively associated to the models.

As a result, all these models share several drawbacks. First, while it is apparent that consumers' vehicle choices are related to age, and that aging population will be the most

¹⁷ IFSD is maintained by the Energy Sector of NRCan, and used for producing Canada's Energy Outlook.

¹⁸ TEDM is produced and maintained by the Energy Sector of NRCan, used primarily for energy market research.

distinctive characteristic of Canada's changing demographic profile in the coming decades, none of these models are capable of tracking this change in relation to vehicle market share. Second, for the choice of some classes of vehicles, such as small and large trucks, occupation is conceivably an important factor in the purchase decisions. Any shift across classes could be very difficult for some areas, since a certain class of vehicle may be found of particular use there due to the prevailing occupation in those areas (e.g. large pick-up trucks for agriculture). On the other hand, significant changes in occupation, which are likely to happen in some regions in the coming decades (Boothby et al. 1995), may naturally result in across-class shifts. None of these models is sensitive to this factor either. Third, vehicle price obviously affects vehicle choice decisions. Price is therefore an effective levy that policy makers can use to induce, directly or through vehicle manufacturers, the market penetration of fuel efficient technologies. Again, none of these models is capable of directly assessing the sensitivity of market share to vehicle price changes.

In addition, all these models share one commonality – a high level spatial aggregation. The IFSD and TEDM models are aggregated to the provincial or regional level. All the other models, which were developed based on American data and calibrated to Canada's data or forecast, are currently used in Canada for national-level forecasting. Huge spatial diversity, however, exists within Canada's vast landmass, as well as within each province/territory. There is a variety of culture, demographics, economy and geographical factors, all of which are related to vehicle choice decisions. For instance, sport utility vehicles may be favoured in one region as a cultural preference, and in another because of variations in topography. A clear understanding of these relations would help policy makers evaluate the potential effectiveness of policy measures aimed at shifting vehicle sales mix. It would also provide a basis for assessing the potential impacts of the policy measures on different regions as well as different demographic groups – the factors that principally should be taken into consideration in all sustainable development policy-making. All these models, however, lack the capacity to enable policy makers to gain such an understanding.

The need to depict spatial diversity in vehicle choice decisions is further justified by the importance of informed GHG policy decision making at the municipal level. Population is concentrated in municipalities. Policy actions at the municipal level are therefore critical to GHG reductions. Policy makers at the municipal governments require analytical tools for policy scenario assessment as well as for tracking progress. Again, the inadequacy in time-series data makes the conventional econometric approach difficult to use for model building. Even if data is adequate, it would be extremely time-consuming to construct models for each municipality, which is required for this modelling approach.

To many of these shortages and drawbacks, a spatial statistics approach provides a potential solution. With spatial regression as the modelling methodology and spatial data as sample observations, a spatial statistics approach can make use of a wealth of socio-economic and environmental data that are made available through a variety of data acquisition methods, such as Census, statistical surveys, remote sensing and field measurements. As such, there is a good possibility that the data limitation for other modelling approaches can be overcome, or mitigated, to some degree. At the same time, without the need to develop models for each area of policy assessment, this approach is capable of producing projections at the level of spatial aggregation appropriate for policy-making, as long as the primary data are available at that level. It is therefore of particular value for assessing spatial diversity in policy-making, as well as for local level policy assessments. To date, however, no effort has been observed to apply this approach to the greenhouse gas policy domain, or even more broadly, to the climate change and sustainable development policy contexts (c.f. Section 9.3). Thus, this case study, which explores the feasibility of the spatial approach to new LDV sale mix modelling, provides policy makers with a new modelling alternative, which could potentially facilitate the development of a more powerful analytical tool in support of policy development.

Chapter 11

Objectives of the Case Study

The objectives of this case study are twofold. Broadly, the study is aimed at exploring the feasibility of using a spatial approach to developing econometric models in support of national policy-making aimed at sustainable development. Particularly, it is aimed at developing new light duty vehicle sales mix models and baseline forecast, at the levels of disaggregation required for policy analysis in support of transportation energy policy-making dealing with climate change.

11.1 The Exploration of the Feasibility of A Spatial Approach to Predictive Modelling in Support of Policy Scenario Assessments

Through this study, a spatial approach will be regarded as a feasible approach to model development in support of policy-making, if the following requirements are met: the modelling tools are adequate; the forecasting methodology is acceptable; the models are capable of supporting policy scenario projection, and the data is adequate. Accordingly, the following research questions will be answered through this research.

- (1) Adequacy of modelling tools.* Theoretically, it has been well understood that spatial regression (or spatial econometrics) is superior to conventional regression in developing models based on spatial data (Anselin 1989, Haining 1990). Practically, however, for the development of policy decision support models, two methodological questions remain. The first deals with the modelling tools. None of the commercial statistical software available on the market has included the spatial regression techniques yet. The only software available for this purpose is SpaceStat, a research package developed by U.S. NCGIA (National Centre for Geographic Information and Analysis). This package, however, deals only with computations. A wide range of spatial exploratory data analysis, which is required in order to obtain good model specifications, needs to be performed within a GIS or other

visualization packages. It remains to be explored as to whether and how a GIS or other visualization package can be used in cooperation with SpaceStat to achieve the derived results. Second, while a range of spatial regression models is available in SpaceStat, each model assumes the existence of only one spatial effect, e.g. spatial error dependence (*c.f.* Section 12.2.1). In reality, however, it is conceivable that spatial error dependence and spatial lag dependence (*c.f.* Section 12.2.1) may co-exist. The method for specifying such complex spatial effects remains to be explored.

- (2) *Validity of forecasting based on spatial econometric models.* It is more common to use models developed on the basis of time-series data for forecasting over the time dimension. The conventional econometric approach is a typical example. The spatial econometric approach, like the discrete choice approach, uses non-time-series data (or cross-sectional data) for estimating models, which are then used for forecasting. The underlying assumption of both these approaches is that the structure of relevant variables remains unchanged over time. Although this assumption is very often made in time-series-based forecasting as well, it seems less straightforward to understand the rationale of this assumption for the non-time-series based approach. Therefore, this study also attempts to verify the validity of spatial econometric models for forecasting.
- (3) *Capability of supporting policy scenario assessments.* Models in support of policy assessments need to be sensitive to policy options (e.g. fuel tax). For this purpose, the relevant policy variables must be included in the models. It remains to be explored as to whether this need can be addressed using a spatial statistics approach.
- (4) *Adequacy of Data.* While a range of spatial data sets are available, or potentially available, for the model development, some variables that are available for conventional econometric modelling may become ineffective in the context of spatial statistical modelling. This is because a spatial econometric approach essentially relies on the variation of data values over space for model specifications. This variation may not exist for some variables, such as business lending rates. For some other variables, such variation may exist, but is unsatisfactory due to the inappropriate levels of data aggregation (for example, fuel price is available only by

province and by major cities). More importantly, it is questionable whether adequate information is available for *explaining* consumers' choice of vehicle size classes. Therefore, an experiment is needed in order to confirm the adequacy of data for producing satisfactory policy decision support models.

11.2 To Develop Spatially-based New LDV Sales Mix Models at the Levels of Disaggregation Required for Policy-making

With the general objective of a feasibility study, this case study will particularly be devoted to the development of Canadian new LDV sales mix models, at the levels of spatial and vehicle disaggregations required for supporting policy scenario assessments. More specifically, this modelling effort will have the following objectives:

- (1) To develop new LDV market share models, based on the level of spatial aggregation appropriate for policy analysis for both large urban centres and the areas of particular policy interest, including the Windsor-Quebec corridor and the lower mainland of BC;
- (2) To disaggregate LDV into 14 classes, as required by policy makers, according to the U.S. EPA's (Environmental Protection Agency) size classification;
- (3) To incorporate as many policy variables as possible into the models, in order to make the models capable of supporting policy scenario assessments; and
- (4) To identify the major determinants to users' new LDV choice decisions, through the model development.

11.3 To Test and Showcase the Capability of the Spatially-based New LDV Sales Mix Models for Policy Scenario Forecast

To test, and meanwhile showcase, the suitability of spatially-based predictive models for policy scenario forecasting, this study will further perform a business-as-usual forecast of

new LDV sales mix for the years 1992¹⁹ to 2010, followed by a forecast of gasoline tax increase scenarios, based on the models developed. Particularly, the forecast will meet the following objectives:

- (1) To produce the forecast of new LDV market share at the local level, and summarize it to the provincial and national levels;
- (2) To derive average new LDV fuel intensity at all these levels of spatial aggregation, to serve as a comprehensive indicator for policy assessments; and
- (3) To estimate the potential effects of gasoline tax increase options (by \$0.05 and \$0.50) on average new LDV fuel intensity.

¹⁹ The data for modelling is for 1991. The forecast is therefore started from 1992 to show the continual trends.

Chapter 12

A Conceptual Framework

To meet the objectives of this case study, a conceptual framework was designed and refined for modelling and forecasting LDV sales mix and fuel efficiency. It covers the definition of spatial units as observations for constructing spatial data samples, the general forms of spatial statistical models, The choice of predicted and predictor variables, and the logistics of model estimation and forecasting.

12.1 Construction of Spatial Data Samples

The estimation of spatial statistical models relies on spatial data samples. A spatial sample consists of values of observations corresponding to spatial units. For example, if eco-regions are chosen as spatial units, one observation represents a particular eco-region (equivalent to the year commonly used in standard econometric modelling).

Given the fact that such regions as urban centres, Windsor-Quebec corridors and the lower mainland of BC are of particular interest to policy assessments, Census Divisions of Canada, which are equivalent to the former (urban centres) and can be aggregated into the latter, were chosen as the spatial units for this modelling exercise. Across Canada, there are a total of 291 Census Divisions (CD). Because of data inadequacy, the seven CDs covering Yukon, Northern Territories, and Nunavut have been excluded from the samples. As a result, all the spatial data samples used in the modelling exercise consist of 284 observations, covering the ten provinces of Canada.

Variables that are available at lower levels of spatial aggregation, such as vehicle registrations, are aggregated into Census Divisions. For those variables (such as provincial tax) that are only available at higher levels of geography, disaggregation is performed on the assumption of a uniform distribution within each geographical unit (*c.f.* Chapter 13 and Section 14.1 for details).

12.2 General Specifications of Spatial Econometric (Regression) Models

Based on spatial data samples at the Census Division level, spatial regression models can be estimated based on a variety of model specifications. A core issue is the methodology for dealing with spatial effects, namely spatial dependence and spatial heterogeneity (Anselin 1988).

12.2.1 Concepts of Spatial Effects

Spatial dependence refers to the dependent relationship between spatial objects. Such dependence violates the assumption of independent observations made for standard regression models. Two broad classes of conditions would lead to this dependence. The first follows from the importance of space as an element in structuring explanations of human behavior. As a result, what is observed at one point is determined in part by what happens elsewhere in the system, with closer points having a larger power of determination. The second factor is a byproduct of measurement errors for observations in contiguous spatial units. Spatial aggregation which is inconsistent with the spatial scope of the phenomenon under study, for example, is one contribution to this problem.

Spatial heterogeneity is related, as a result of model estimation, to the problem of non-spherical error variance (termed heteroskedasticity), namely the error variance of a model varies with space. It violates another key assumption of standard regression models - spherical error variance (or homoskedasticity). Likewise, spatial heterogeneity has two primary sources. One is the lack of stability over space of the behavioral or structural relationships under study. Functional forms and parameters therefore need to properly vary with locations; otherwise heteroskedasticity results. For instance, this is likely to occur in econometric models estimated on a cross-sectional data set of dissimilar spatial units, such as Southern and Northern Canada. The second source lies in the heterogeneity of spatial units of observation themselves. For example, regions have different income levels and various degrees of technological development. To the extent

that these aspects of heterogeneity are reflected in measurement errors (missing variables and functional mis-specification), they may result in heteroskedasticity.

Also, the complex interaction resulting from spatial flows (the major source of dependence) and spatial structures (the major source of heterogeneity) may generate dependence in combination with heterogeneity. While the tools provided for handling heterogeneity problems in standard econometrics are still valid, a specific spatial econometric approach is necessary, in order to deal with most of the spatial effects.

12.2.2 Forms of Spatial Regression Models

To this end, a range of spatial regression models have been devised, with an array of statistical testing techniques available to assist in model specification and validation (Anselin 1988). In general, a spatial regression model can be formulated as follows:

$$y = \rho Wy + X\beta + \varepsilon \quad (\text{Equation 12-1})$$

$$\varepsilon = \lambda W'\varepsilon + \mu$$

with $\mu \sim N(0, \Omega)$

and the diagonal elements of the error covariance matrix Ω as:

$$\Omega_{ii} = h_i(z\alpha) \quad h_i > 0.$$

In this specification, β is a K by 1 vector of parameters associated with exogenous variables X (N by K matrix), ρ is the coefficient of the spatially lagged variable, and λ is the coefficient in a spatial autoregressive structure for the disturbance (residuals) ε .

This disturbance of ε is taken to be normally distributed with a general diagonal covariance matrix Ω . The diagonal elements allow for heteroskedasticity as a function of

$P+1$ exogenous variables z , which includes a constant term. The P parameters α are associated with the non-constant terms, such that, for $\alpha = 0$, it follows that

$$h = \sigma^2,$$

i.e., the classic homoskedastic situation.

The two N by N matrices W and W' are spatial weight matrices representing the spatial relationships between spatial units, respectively associated with a spatial autoregressive process in the dependent variable and in the disturbance term.

Simplified models result when different constraints are imposed:

For $\rho = \lambda = \alpha = 0$ ($P+2$ constraints):

$$y = X\beta + \varepsilon \quad (\text{Equation 12-2})$$

namely, the standard linear regression model, with no spatial effects.

For $\lambda = \alpha = 0$ ($P+1$ constraints):

$$y = \rho Wy + X\beta + \varepsilon \quad (\text{Equation 12-3})$$

namely, the mixed regressive-spatial autoregressive model dealing with spatial lag dependence.

For $\rho = \alpha = 0$ ($P+1$ constraints):

$$y = X\beta + (I - \lambda W')^{-1} \mu \quad (\text{Equation 12-4})$$

namely, the linear regression model with a spatial autoregressive disturbance.

For $\alpha = 0$ (P constraints):

$$y = \rho W y + X\beta + (I - \lambda W)^{-1} \mu \quad (\text{Equation 12-5})$$

namely, the mixed-regressive-spatial autoregressive model with a spatial autoregressive disturbance.

For each of the models from 12-2 to 12-5, different specifications are obtained by allowing heteroskedasticity of different forms (i.e., $h(z\alpha)$). Three forms of heteroskedasticity specification are generally used: (1) generic heteroskedasticity in which heteroskedasticity is expressed by a function of exogenous variables; (2) groupwise heteroskedasticity in which error variance is assumed to vary with a given number of groups while, within a group, the errors are homoskedastic; and (3) random coefficient variation which takes the square of explanatory variables being used to construct the function of $h(z\alpha)$.

In each of the above models, including the models from 12-2 to 12-5 and the combinations of these models with the different forms of heteroskedastic specifications, spatial heterogeneity in the forms of varying functional forms or changing regression coefficients can be incorporated in such forms as spatial regimes and spatial expansion, thus yielding many more forms of spatial regression models.

In the case of heterogeneity that can be categorized into a small number of regimes, each represented by different values for the regression coefficients and/or different explanatory variables, the regression model takes the form of spatial regimes (switching regression). For example, in a two-regime case for the most simplified linear regression:

$$\begin{aligned} y_i &= X_i \beta_i + \mu_i \\ y_j &= X_j \beta_j + \mu_j \end{aligned} \quad (\text{Equation 12-6})$$

where i and j refer to the respective regimes.

For the heterogeneity in the form of continuous coefficient variation, spatial expansion methods can be incorporated into the model. The continuous drift in the parameters can be formulated as a function of a set of auxiliary variables, which can be any set of variables, including polynomial expressions such as a trend surface. For example, without loss of generality, for the simplest linear regression model with one explanatory variable

$$y = \beta_0 x + \varepsilon$$

If the coefficient of x continuously varies with locations, it can then be expanded as:

$$\beta_0 = g(z\alpha)$$

Thus, $y = g(z\alpha)x + \varepsilon$ (Equation 12-7)

In situations where no obvious variables are available to determine a specific form of parameter variation, the set of explanatory variables for the model can be used, on the assumption that the coefficients for individual observations are random drawings from a multivariate distribution (Anselin 1988 p130). This results in the random coefficient approach equivalent to the random coefficient specification of heteroskedasticity.

12.3 Choice of Predicted Variables

This modelling exercise is aimed at predicting new LDV sales mix, with new LDV sales to be predicted to allow for the aggregation of the sales mix predictions from the Census Division level into the provincial and national levels.

For the sales mix models, the predicted variables can be defined in three ways: new vehicle market share of total new light duty vehicles; the shares of cars/trucks; and the

market share of passenger cars/cargo trucks. The first choice represents a total market partition. The second is more suitable for examining average vehicle fuel intensity improvements in comparison with the CAFC standard. And the last is found to be more reasonable in reflecting sales mix shift. Although all these choices have been tested for model estimation, the market share of total LDVs were eventually chosen for two reasons. First, this type of market share generally yields model estimates superior to those from the other types of market share. Secondly, all the other types of market share can be derived from these estimates.

With regard to the new LDV sales model, the predicted variable can be defined as the number of sales directly, or as new household LDV ownership, which can further be converted into sales numbers by multiplying it with the number of households. Both have been tested in the modelling process. The first choice was made as it led to a superior model.

12.4 Choice of Predictor variables

Based on the general forms of spatial regression models, the predicted variables of new LDV vehicle market share and sales can be estimated, using appropriate explanatory (or predicting) variables. The choice of the explanatory variables is determined by the considerations that consumers generally give in their vehicle class choice decisions.

12.4.1 Predictor variables for LDV Market share Models

According to a review of relevant models and literature²⁰ and an analysis of the factors associated with new LDV sales mix, consumers choices of vehicle size class can mostly

²⁰ Effort has been made to search the literature and models addressing vehicle sales mix modelling. However, it appears that such modelling effort is very limited, so is the pertinent literature. The relevant literature used includes J.D. Power's Outlook for Canadian Light Vehicle Market (Ballew 1996), Phase 5 Consulting Group's research (1994) related to the fuel consumption guide and fuel consumption labels, the survey on Canada Car Driving Perception and Attitudes toward Fuel Efficiency conducted by Larry Johnson Communications (1992), International Environmental Monitor (1990-96), Oak Ridge National Laboratory's Light-duty Vehicle MPG and Market share Report (1989), and two books on car ownership modelling, by Train (1986) and by Botton et al. (1982) respectively. The major models reviewed include the Fuel Economy Model developed by Energy and Environmental Analysis Corporation for US

be attributed to demographic, economic, vehicle characteristics, geographic, and temporal factors. Demographic characteristics such as population age, to a large extent, determine the personal preference for vehicle class; while economic, demographic and vehicle characteristics contribute to vehicle purchase decisions explained by utility maximization theory. The concept of utility may be extended to include the prestige of driving a particular class vehicle.

Geographical characteristics are often taken into consideration in vehicle size choice, since, for example, larger size vehicles are normally more suitable for rural driving and small ones for urban driving. Temporal autocorrelation is another factor that may largely affect consumers' vehicle purchase decisions. It is conceivable that if large size cars are favored in an area in a certain year, it is very likely that this size class will enjoy some level of popularity there in the following year as well. Additionally, environmental concern might also be considered in consumers' choice of vehicle class (c.f. Section 12.4.3).

All these variables could be considered in the modelling exercise. Whether they can be tested, however, also depends on such factors as the presence of spatial variation in the factor, and the availability of data.

The presence of variation over space is a prerequisite for a spatial variable. This property, however, is not found in some variables, especially the vehicle characteristics variables. For example, a certain class of vehicle has an average vehicle volume, passenger space or luggage volume, all of which do not vary with space. Business lending rates are primarily uniform over different regions as well. These variables therefore cannot be used in spatial statistical modelling. In some cases, however, aspatial variables, namely the variables whose values do not vary with space, can be transformed into a spatial form. For example, vehicle class fuel efficiency is aspatial, but it can be combined with fuel price to form the spatial variable of fuel cost. Aspatial variables with

clear local characteristics can be transformed into spatial ones as well, such as vehicle “prestige” and the number of customized vehicle name plates, which can be transformed into values in relation to local averages.

With regard to data availability, some variables that are possibly related to consumer’s vehicle purchase decisions were not chosen for testing due to the lack of data. Vehicle operating cost other than fuel use is an example of this. Moreover, while the wealth of information provided by Canadian Census allowed the testing of a variety of demographic variables as potential explanatory variables, for the purpose of forecasting, preference was given to those variables for which projected data are available. This is because projections are needed for all the explanatory variables in order to produce vehicle sale mix forecast, but modelling and forecasting for explanatory variables would far exceed the scope of this project.

Based on the above considerations, over ten groups of variables, as shown in Table 12-1, were used to test the significance of their correlation with vehicle class mix. With different variables in each group and different measures for the same variable, over one hundred variables have been tested altogether, in order to obtain a good representation of new LDV sales mix. According to the models and literature reviewed, it is the first attempt to incorporate occupation, ethnicity groups, and road conditions in vehicle market share modelling. Occupation and ethnicity groups are thought to be relevant, for the possibilities of different occupational needs for vehicles, and cultural differences in vehicle favorability, respectively. Road condition is considered since such vehicles as small utilities and pickup trucks are more suitable for rough road driving than others. In addition, for policy test considerations, a relative measure of vehicle purchase and fueling cost was constructed to represent the factor of vehicle cost, based on vehicle and fuel price, fuel efficiency and annual vehicle kilometers traveled. The construction of such a compound variable allows for the representation of multiple cost-related variables inside the models, thereby potentially enabling the test of multiple policy options with regard to

Table 12-1: Variables tested for modelling new LDV market share

Variable category/ concept represented	Variable group	Examples of variable
Demographic, for personal preference	Population age group	Percentage of population aged from 25-44
	Occupation	Percentage of professional occupations
	Education	Percentage of population with post secondary education;
		Percentage of population with education in sciences
	Ethnicity	Percentage of population with French origin
Economic, demographic, for utility considerations	Gender	Ratio of male/female population
	Income	Average household income;
		Income per capita;
		Percentage of household with income between \$60,000 and \$70,000
	Vehicle cost	Relative vehicle purchase and fueling cost, which is derived from fuel efficiency, distance travelled, and fuel price;
		Family expenditures on vehicles: purchase, fuels, tires, insurance, registration
	Local economic variables	Percentage of household with major payments over 30%
	Household composition	Percentage of household with two or more members in labour force
	Household size	Number of households with 4 or more household members
Geographic, for local suitability	Vehicle "prestige"	Ratio of vehicle prestige to local average vehicle prestige
	Daily driving distance	Urban/rural;
		Population density
	Driving conditions	Standard road density
	Recent local new LDV sales mix	Previous year's new LDV market share
Environmental related, for environmental concern	Population age groups	Percentage of population aged from 55-75;
		Percentage of population aged 25-35
	Education	Percentage of population with post-secondary education;
		Percentage of population majoring in technology and natural sciences;
		Percentage of population majoring in social sciences and health

vehicle ownership and operating cost (c.f. Section 12.4.3 for more details). As well, it allow for the consideration of fuel efficiency technology improvements in policy scenario assessments based on the models.

12.4.2 Predictor variables for New LDV Sales Model

The dominant factors affecting new LDV sales, according to previous models, are such socio-economic variables as numbers of households, household size, household income, and fuel price. New vehicle sales are related to existing vehicle stock as well. Additional relevant factors include vehicle purchase price, public transit access, and vehicle distance travelled. All these variables were tested in modelling new LDV sales. For policy test considerations, a vehicle affordability indicator was constructed, based on income, vehicle purchase and fuel price, average distance travelled, and average vehicle fuel intensity (c.f. Section 12.4.3 for more details).

12.4.3 Special Considerations for Policy Assessments

The ability of models to support policy assessments was a major consideration taken in the choice of explanatory variables. Policy measures that are related to vehicle sales mix models and that are of particular interest in the current policy context have mainly to do with vehicle cost, including both purchasing and operating cost. Immense effort has been made to make models sensitive to such cost variables. Some of the issues involved deserve special notes.

The first is concerned with the ability of models to support policy assessment, especially integrated policy assessment. Vehicle price and fuel price could be highly correlated, as both are made spatial variables by including provincial taxes. This correlation makes it very difficult to include both of the variables in the models, due to the multilinearity effect. This is true as has been proven in this modelling process. The inclusion of both of the variables in a model, however, is necessary, since such a model will enable, in a separate or integrated manner, the assessments of both fuel tax and feebates measures – the important policy measures dealing with vehicle efficiency improvement. A solution to this is the construction of a complex variable that includes both the fuel price and vehicle price variables. The two complex variables, relative vehicle purchase and fueling cost, and average vehicle purchase and fueling cost, partially result from this consideration.

The second issue deals with the ability of vehicle market share models to systematically react to a feebate policy. Conceivably, a feebate policy would cause changes in the vehicle classes directly addressed by the policy, which would in turn cause changes in the market share of other classes. The virtually independent nature of each vehicle class market share model, however, makes this chaining reaction problematic. Therefore, rather than using the variables of fuel cost or vehicle price for different classes, a vehicle cost measure relative to average cost was constructed to reflect the amount of saving gained by owning a particular class of vehicle. Thus, changes in vehicle price for a certain class of vehicle, for example, will result in a change in average vehicle price, which will cause changes in the relative cost measures of other classes of vehicles, thus resulting in a shift within the entire LDV market.

The last issue is concerned with the incorporation of vehicle fuel efficiency technology improvements into the models. Vehicle operating cost is related to fuel efficiency, and the rate of fuel efficiency improvement will differ among different vehicle classes. In the forecast of new LDV market share, it is important that fuel cost take into account the improvement of fuel efficiency technology, as well as the different rate of improvement for different vehicle classes. For this purpose, this study adopted the size-class based fuel efficiency improvement forecast produced by U.S. DOE, but calibrated to NRCan's estimation of annual rate of average new LDV fuel efficiency improvement.

With regard to average vehicle fuel intensity improvements, the average measures of vehicle fuel intensity by cars and by trucks can be calculated at a required level of spatial aggregation, based on the vehicle market share as well as the sales model (c.f. Section 12.5). Similarly, tests can be performed by assuming different levels of technological improvements, and/or different policy measures regarding vehicle and fuel pricing. The resulting values of average vehicle fuel intensity give an idea about the levels of fuel intensity improvement that could result from these policy measures.

In addition, an attempt has also been made to include some environmental awareness indicators into the models, in order to test policy options dealing with environmental education. Numerous driver attitude survey materials were used in an attempt to construct such indicators, including Canada Car Driving Perception and Attitudes towards Fuel Efficiency (Larry Johnson Communications Inc. for NRCan 1992), Research Related to the Fuel Consumption Guide and Fuel Consumption Labels (Phase 5 Consulting Group for NRCan 1994), and the Environmental Monitor (International Environmental Monitor Ltd 1990-1996). A general view from these materials is that people who are younger or with higher levels of education have more environmental concerns (or are more aware of environmental issues) than those who are older or with lower levels of education; but the influence of these concerns are minor on vehicle purchase decisions. This view has been tested in this research, with a hope to elicit some socio-demographic variables as environmental awareness indicators.

12.5 The Logistics of Modelling and Forecasting

Figure 12-1 illustrates the framework of modelling new LDV market share and sales, as well as forecasting the market share and average vehicle fuel intensity, at the Census Division, provincial and national levels.

The basis, and the core, of this framework is model building. The general forms of spatial regression models, as described earlier, were used for the model formulation. The chosen predicting variables were examined, grouped, and tested, in terms of their relationships with new LDV market share and sales, and the relationship among themselves. An attempt was also made to substitute the variables contributing to the models with those which are relevant and for which projected data can be acquired. As a result, only five

Figure 12-3: The framework for modelling and business-as-usual forecasting for new LDV market share, sales and average fuel intensity, at the Census Division, provincial and national levels

types of thematic variables were included in the models, namely household income, age group, occupation, relative vehicle purchase and fueling cost, and population density, with a different combination for each model. Conceptually, the variables of previous year's new LDV market share were included in the models as well (c.f. Section 13.2.1), but they are represented by the above thematic variables and the remaining portions. For the new LDV sales model, the thematic variables eventually used were vehicle stock, total number of household, household income, annual vehicle purchase and fuel cost, and transit vehicle hours serviced (see Appendix 1).

Fourteen models have resulted from this modelling process. Thirteen of them correspond to the 15 vehicle size classes, with the three wagon classes merged into one. The remaining one is a new LDV sales model, which is estimated primarily for the purpose of aggregating new LDV sales mixes from the Census Division level to the provincial and national levels.

Based on the sales and sales mix models, forecasting follows at the Census Division level for new LDV sales and sales mixes, for the forecasting period from 1992 to 2010. The data of explanatory variables in the sales and sales mix models are substituted with their corresponding projected data, and the forecast of sales and sales mix is then computed using the models. An assumption made with this forecasting approach is that there will be no significant changes in the relationships between the predictor variables and the predicted variables during the forecasting period.

The average of projected new LDV market share by Census Division, weighted by the projected new LDV sales at the CD level, leads to the market share forecast at the provincial and national levels. The market share forecast is then used as weights, to derive average new LDV fuel intensity at all these levels of geography, based on the estimated new LDV fuel efficiency improvements by size class (c.f. Section 13.1.2).

The policy scenario forecast on the assumptions of gasoline tax increases is performed within the same forecasting framework, but with assumed gasoline tax increases added to the projected fuel price as pertinent to each new LDV market share model. The potential average new LDV fuel intensity scenarios, derived from the scenario forecast of new LDV market share, are compared to the business-as-usual forecast, to obtain the potential effects of the assumed policy options.

Special attention was paid in the process of forecasting, as well as modelling, to keep the forecast consistent with NRCan's 1997 Energy Outlook by using consistent data. For example, while fuel efficiency technology improvements are considered at a disaggregate vehicle class level in the models, the rates of improvement have been calibrated so that the overall fuel intensity improvement rates are consistent with NRCan's viewpoint (c.f. Section 13.1.2).

Additionally, it is worth noting that, for the variable of transit vehicle hours serviced, no projected data has been found for the forecasting years. An assumption of no change in

this variable is made in the new LDV sales forecasting, according to the relative stability of transit service from 1991 to 1994 (CUTA 1992, 93, 94). In reality, of course, there will be some changes. It should therefore be kept in mind that the sales forecast, to a small extent, will be subject to changes in transit services. Despite this uncertainty, this variable is kept in the model for three main reasons. First, no change in this variable could be implicitly assumed even if this variable were excluded from the model. Second, this variable is expected to be a contributor to the model; its presence in the model makes the relationship explicit and improves the explanatory capability of the models. Lastly, this variable could be potentially useful in testing policy measures dealing with public transit service.

Chapter 13

Variable Definitions and Data Processing

The conceptual framework has outlined the major variables used in modelling new LDV sales and their class mix. The detailed definitions of these variables, and data processing involved in obtaining these variables, are presented in this Chapter. The data processing issues cover both the data for model estimation, namely the 1991 data, and the data for forecasting, ranging from 1992 to 2010. All the notations have the same meaning throughout the thesis, unless otherwise indicated.

13.1 Predicted Variables

In a broad sense, predicted variables refer here to all the variables to be forecast in this case study. Both the variables to be predicted by spatial regression models and those to be derived based on the predicted data are therefore addressed.

13.1.1 Market share of New Light Duty Vehicle by Size Class

New LDV class mix or new LDV market share refers to the market share of new light duty vehicles by size classes, which was based on a size class segmentation used by the U.S. Environmental Protection Agency (EPA; see Appendix 2). They are defined as follows:

For size classes 1 to 6 and 10 to 15,

$$Pepa_{ij} = \frac{100 * Epa_{ij}}{\sum_{i=1-15} Epa_{ij}} \quad (\text{Equation 13-1})$$

where $Pepa_{ij}$ - market share of size class i ;

Epa_{ij} - sales of size class i ;

- i - vehicle size class;
 j - Census Divisions (CD), ranging from 1 to 284.

For size classes 7, 8, 9:

$$Pepa_{ij} = \frac{100 * \sum_{i=7-9} Epa_{ij}}{\sum_{i=1-15} Epa_{ij}} \quad (\text{Equation 13-2})$$

For the estimation of $Pepa_i$ at the Census Division level, the 1991 model-year vehicles extracted from the 1992 Canadian Vehicles in Operation Census database were used as the source for generating the new vehicle sales of size class i by CDs. The market share by CDs from 1992 to 2010 was projected based on the estimated models.

The new LDV market share at the provincial level was obtained based on the new LDV market share and sales at the CD level, namely:

$$Pepa_{ip} = \frac{\sum_{j=m-n} (Pepa_{ij} * ns_j)}{\sum_{j=m-n} ns_j} \quad (\text{Equation 13-3})$$

- where p - a province of Canada; Atlantic provinces are grouped into one region;
 ns_j - new LDV sales at CD j ;
 m, n - the starting and ending CD numbers of p .

The ns_j were predicted based on the new LDV sales model, for which the sums of all 1991 model-year vehicles registered in 1992 provided the data for the predicted variable new LDV sales.

By defining $m = 1$ and $n = 284$, Equation 13-3 yields the new LDV market share at the national level.

13.1.2 Average New LDV Fuel Intensity

The average light duty vehicle fuel intensity refers to the average litre per 100 kilometers of all new light duty vehicles. It is converted from a linearly weighted average of vehicle fuel efficiency by size class:

$$afi_j = 235.21 * 100 / \sum_{i=1-15} (fe_i * Pepa_i) \quad (\text{Equation 13-4})$$

where afi_j - average LDV fuel intensity in location j ;

fe_i - average fuel efficiency of vehicle class i (miles per gallon);

j - CD, province or Canada;

235.21 - a coefficient for converting fuel efficiency (miles per gallon) into fuel intensity (litre per 100 kilometers).

Given its ability to derive average fuel efficiency for each new LDV size class, the Vehicle Fuel Economy Information System (VFEIS, see Appendix 1 for more details) at the Energy Sector was used as the data source for the variable of fuel efficiency fe_i for the years 1991-1993. For the years from 1994 to 2010, this data was derived based on two data sources: the Energy Sector's estimates of average new LDV fuel intensity from 1994 to 2010; and the fuel efficiency projection by vehicle size class from 1993 to 2010, based on the Fuel Efficiency Model (FEM) at the US Department of Energy (DOE 1996, Decision Analysis Corp. of Virginia and Energy and Environmental Analysis Inc. for DOE 1996).

To derive the projected fuel efficiency data, the 1993 fuel efficiencies by size class from VFEIS were used as the initial fuel efficiency values, and the fuel efficiencies for the following years were calculated by adding incremental changes to the initial values. The incremental improvements were calculated by using the class-based improvement rates

estimated by DOE, calibrated by the aggregate estimates of fuel efficiency improvement rates by the Energy Sector, namely:

$$fe_{iy} = fe_{iy-1} + fe_{iy-1} * (feir_{doe_{iy,y-1}} - delta_{rate_{y,y-1}}) \quad (\text{Equation 13-5})$$

where fe_{iy} and fe_{iy-1} - average fuel efficiency estimates for class i for the years y and $y-1$ respectively;

$feir_{doe_{iy,y-1}}$ - fuel efficiency improvement rate for size class i from the year $y-1$ to y projected by DOE. It is derived by

$$feir_{doe_{iy,y-1}} = (fe_{doe_{iy}} - fe_{doe_{iy-1}}) / fe_{doe_{iy-1}} \quad (\text{Equation 13-6})$$

where $fe_{doe_{iy}}$ and $fe_{doe_{iy-1}}$ stand for fuel efficiency estimates for size class i for the year y and $y-1$ respectively;

$delta_{rate_{y,y-1}}$ - difference in aggregate fuel efficiency improvement estimates between Energy Sector and DOE, i.e.:

$$delta_{rate_{y,y-1}} = (fe_{es_y} - fe_{es_{y-1}}) / fe_{es_{y-1}} - (fe_{doe_y} - fe_{doe_{y-1}}) / fe_{doe_{y-1}} \quad (\text{Equation 13-7})$$

where fe_{es_y} and $fe_{es_{y-1}}$ stand for aggregate fuel efficiency estimates for the years y and $y-1$ respectively by NRCAN; and fe_{doe_y} , $fe_{doe_{y-1}}$ for the same estimates by U.S. DOE;

y - a predicting year, ranging from 1994 to 2010 in this context.

13.2 Predictor variables

13.2.1 Previous Year's New LDV Market share by Census Division

For each Census Division, it is conceivable that a temporal inheritance exists in new LDV sales mix. In general, such inheritance (or temporal autocorrelation) is most evident in two succeeding years. By including such a variable in the model, a new vehicle market share model must be improved. This has been confirmed in the current modelling process. A problem observed from the process, however, is that the correlation between 1990 and 1991 market share at the Census Division level are so significant that the 1990 market share absolutely dominate the 1991 market share model, with large portions of socio-economic and vehicle cost contributions to the model taken over by this variable. This dominance could cause many problems. Among others, changes in socio-economic and vehicle related factors would have little representation in the new LDV market share forecast. As well, policy assessments would become problematic, since the models would be insensitive to changes in policy measures.

To resolve this problem and, at the same time, to utilize the power of the temporal inheritance, the variable of previous year's new LDV market share was decomposed into two main components: the component explained by socio-economic factors, and that explained by other factors, such as cultural preferences and comprehensive geographical suitability. Spatial regression models were used to obtain the functions of this decomposition for each size class. Specifically,

$$Pepa_{ijy-1} = \Psi(se_c_{jy-1}, o_c_{jy-1}) \quad (\text{Equation 13-8})$$

where $Pepa_{ijy-1}$ - the previous year' market share of CLASS i in CD j ;

o_c_{jy-1} - other components including cultural preferences and comprehensive geographical suitability for vehicle classes in CD j in the previous year $y-1$.

se_c_{jy-1} - socio-economic and vehicle related factors in CD j in the previous year $y-1$;

Assuming that $se_{c_{jt-1}}$ and $o_{c_{jt-1}}$ are independent from each other in explaining the market share, then

$$Pepa_{ijt-1} = \Psi'(se_{c_{jt-1}}) + \Psi''(o_{c_{jt-1}})$$

Given that socio-economic factors are closely correlated between two succeeding years, the first term of the equation can mostly be explained by the socio-economic factors in the succeeding year, namely,

$$se_{c_{jt-1}} = \Phi(se_{c_{jt}}) + \xi$$

Thus, the market share of the previous year can be expressed as a function of the succeeding year's socio-economic and vehicle related factors, plus the same function of the random errors resulting from the regression between the two year's socio-economic and vehicle related variables, and a component not related to these factors, i.e.:

$$Pepa_{ijt-1} = \Psi'(\Phi(se_{c_{jt}})) + \Psi'(\xi) + \Psi''(o_{c_{jt-1}})$$

It is reasonable to assume that the last term within this equation will remain primarily unchanged over the forecasting period, since significant changes in cultural preferences and comprehensive geographical suitability are unlikely to happen in two decades. Likewise, it is presumable that there will be no significant difference in residuals resulting from the regressions between two succeeding years socio-economic and vehicle related variables. Thus the two last terms of this equation can be joined together, forming a variable representing the relatively stable factors associated with local market share of new LDV sales. The previous year market share can therefore be explained as:

$$Pepa_{ijt-1} = \Omega'(se_{c_{jt}}) + \Omega''(oc_{jt}) \quad (\text{Equation 13-9})$$

where $Pepa_{ijt-1}$ - previous year's market share of class i in CD j ;

- se_{cjt} - present-year socio-economic factors in CD j related to the previous year's new LDV market share;
- oc_j - other local factors in CD j associated with previous year's new LDV market share, typically including cultural preferences, comprehensive geographical suitability, and residuals resulting from the regression between two succeeding year's socio-economic and vehicle related factors.

13.2.2 Relative Vehicle Purchase and Fueling Cost

The variable of relative vehicle purchasing and fueling cost represents the annual difference in the cost of purchasing and fueling a vehicle of a particular class from the average vehicle purchase and fueling cost. It is defined as:

$$an_pfs_{ij} = an_vps_{ij} + an_vfs_{ij} \quad (\text{Equation 13-10})$$

That is, the cost difference an_pfs_{ij} for each CD j has two components: the difference in vehicle purchase an_vps_{ij} , and the difference in fuel cost an_vfs_{ij} . an_vps_{ij} is defined as the difference between the average light-duty vehicle price and the average class i vehicle price, allocated to three years (assuming that the financial influence on the consumer in purchasing a vehicle would span a three year period) :

$$an_vps_{ij} = (vprice_ave_j - vprice_{ij})/3 \quad (\text{Equation 13-11})$$

where $vprice_ave_j$ and $vprice_{ij}$ stand for average light duty vehicle price and average class i vehicle price in CD j , respectively, where vehicle price consists of manufacturing suggested price and provincial tax ²¹.

²¹ It was also attempted to derive the vehicle price data from the 1992 Family Expenditure Survey by Statistics Canada. On the assumption that the ratio of class i vehicle price to the average light duty vehicle price remains constant over all economic regions (over 70 regions across Canada), the aggregate measure of family expenditure on vehicle purchase was disaggregated into one by 15 size classes. The same process was applied to vehicle operating cost and other vehicle cost such as vehicle insurance and registration. However, modelling tests using size class 3, 4, 6 and 13 mostly did not result in coefficients with expected signs for these variables. The definition of the vehicle related variables an_pfs_{ij} , as well as the data

an_vfs_{ij} is defined as the difference between average annual light-duty vehicle fuel cost and average class i vehicle fuel cost, multiplied by vehicle distance traveled (vdt), namely:

$$an_vfs_{ij} = (fcost_ave_j - fcost_{ij}) * vdt_j \quad (\text{Equation 13-12})$$

where $fcost_ave_j$ and $fcost_{ij}$ stand for average light-duty vehicle fuel cost and average class i vehicle fuel cost in CD j , and defined respectively as:

$$fcost_ave_j = fuel_price_j / (fe_ave * 42.52) \quad (\text{Equation 13-13})$$

$$fcost_{ij} = fuel_price_j / (fe_i * 42.52) \quad (\text{Equation 13-14})$$

where fe_i stands for the average vehicle fuel efficiency of size class i , and fe_ave for the mean of the average vehicle fuel efficiencies of all size classes. Since the unit is cents per ltr. for the source fuel price data, kilometers per year for the vehicle miles traveled data, and miles per gallon for the fuel efficiency data, the constant 42.52²² is applied to convert the unit of the equation into dollars per year.

The data for manufacturing suggested vehicle price was obtained from the Department of Energy, US. The original data is disaggregated into domestic and import groups, and available by 12 vehicle size classes which are consistent with the 15 size classes used by the Energy Sector, with the large car and all wagon classes merged into one class. The domestic and import prices have been aggregated, according to the U.S. new vehicle sales data set (1990) coming along with the price data²³. For the years from 1991 to 1993, the original domestic and import vehicle prices by 12 size classes were converted from those

including fuel price (from the Energy Sector), manufacturing suggested vehicle price (from U.S. DOE), provincial tax (from Statistics Canada), fuel efficiency (intensity) improvements (from U.S. DOE and the Energy Sector), and annual vehicle distance travelled (from the Energy Sector), provides an effective alternative to the problem.

²² $x \text{ (MPG)} = x * 1.6093/3.785 \text{ (km/ltr.)} = 0.4252x \text{ (km/ltr.)}$

²³ It should therefore be noted that vehicle price is approximate. More pertinent data could result, for example, by using Canada's new vehicle sales data categorized into domestic and import vehicles in deriving the average vehicle price.

of 14 vehicle classes provided by Duleep (DOE 1996) (according to a conversation with David Chien at DOE). For all other projecting years, these prices were converted from the estimates produced by the DOE's Fuel Efficiency Model (FEM) (DOE 1996), which takes both technology and performance improvements into consideration. For the provincial tax component, the 1991 data were obtained from Statistics Canada, and these tax rates are assumed to remain unchanged over the projecting period.

The data for fuel price by province and urban centres for 1991 was obtained from the Energy Sector. A provincial fuel price was assigned to each Census Division in that province, except for the urban centres where the particular fuel price data are available. Fuel price forecast by province for all the projecting years was produced by the Energy Sector in March 1996. They were assigned to the Census Divisions within the corresponding provinces.

The data for vehicle distance traveled, available by province, were provided by the Energy Sector as well. Produced by Informetrica Limited, the estimates are disaggregated into two groups: passenger cars and cargo trucks. These provincial estimates were directly applied to the Census Division level due to data limitation.

13.2.3 Total Number of Households

The definition of household follows that used in Canada's 1991 Census. The data for the variable of total number of household was derived by assigning Informetrica's estimate of the provincial number of households (used by Energy Sector) to a Census Division, proportional to the household number of that Census Division in that province, according to the Canadian Census for 1991 and to CompuSearch's estimates for the years from 1992 to 2010, namely:

$$a_{hoh_j} = hoh_{inf_p} * hoh_{cs_j} / hoh_{cs_p} \quad (\text{Equation 13-15})$$

where a_{hoh_j} - the calibrated number of households in CD j for the year y ;
 hoh_{inf_p} - number of household in year y in province p estimated by

Informetrica;

hoh_{cs_j} - for 1991, number of household in CD j according to 1991 Census; for the years 1992 to 2010, number of household in CD j projected by CompuSearch;

hoh_{cs_p} - for 1991, number of household in province p according to 1991 Census; for the years 1992 to 2010, number of household in province p , projected by CompuSearch.

13.2.4 Average Household Income

Average household income is defined as the total personal income in Census Division j , divided by the total number of household in that CD:

$$a_{hinc_j} = a_{tpinc_j} / a_{hoh_j} \quad \text{(Equation 13-16)}$$

where a_{hinc_j} - average household income in CD j ;

a_{tpinc_j} - total personal income in CD j

For 1991, the data for a_{tpinc_j} was derived by assigning the provincial total personal income estimated by Informetrica to CD j , proportional to the total personal income of CD j in the total personal income of that province, according to the 1991 Census. This proportion was replaced with that according to CompuSearch's projection, for the years from 1992 to 2010. Total personal income by CD, for both the 1991 Census and CompuSearch's projections, was derived by multiplying household average income with the total number of household provided in these data sets.

13.2.5 Population Age Group

A population age group is defined as the percentage of population within a certain age range in the total population in a given area. Four age groups were found to be particularly relevant to the choice of vehicle class, namely ages 25-44, 30 - 44, 55-75 and

65-75. The 1991 Census was used to generate the age groups for 1991, and CompuSearch's population projections for 1992 to 2010.

13.2.6 Occupation

The definition of occupation used in the 1991 Canadian Census is adopted in this research. It is consistent to the 1990 National Occupation Classification (Statistics Canada 1991 p69). While many occupations were tested in the modelling process, only the farm and forestry occupations have eventually been included in the models. The 1991 Census provides the data source for the year 1991. For projected data, the occupation projection for the years 1991, 1996, 2000 and 2005, produced by the Canadian Occupation Projection System (COPS) at Human Resources Development Canada (Boothby et al. 1995), was obtained for farming and forestry occupations, as well as the total numbers of occupation. A polynomial curve at the third order (Equation 13-17) was fit for each province, according to the COPS' four-year's projection for the percentages of farming and forestry occupations.

$$oc_x_tp_{py} = a0 + a1 * year^1 + a2 * year^2 + a3 * year^3 + \varepsilon \quad (\text{Equation 13-17})$$

where $oc_x_tp_{py}$ - the percentages of farming or forestry occupation projected for province p for the four projected years, 1991, 1996, 2000 and 2005.

$year$ - the four projected years, equivalently replaced by 1, 6, 10 and 15.

Based on these curves, the percentages of farming and forestry occupations were projected (or interpolated) for all the years from 1992 to 2010, with the projections for the four originally projected years exactly fit. On the assumption that the proportions of farming and forestry occupations of each Census Division in the corresponding province remain unchanged, the provincial occupation projections were then assigned to each Census Division, according to the proportion of the occupation of that Census Division in the province based on the 1991 Census:

$$oc_x_tp_{jy} = oc_x_tp_{py} * (oc_x_tp_{j91}/oc_x_tp_{p91}) \quad (\text{Equation 13-18})$$

where $oc_x_tp_{jy}$ - the projected percentages of farming or forestry occupation in the Census Division j for the year y ;

$oc_x_tp_{j91}$ - the percentage of farming or forestry occupation in CD j in 1991;

$oc_x_tp_{p91}$ - the percentage of farming or forestry occupation in province p in 1991.

13.2.7 Population Density

The variable of population density is defined as:

$$a_pop_d_j = a_pop_j/area_j \quad (\text{Equation 13-19})$$

where $a_pop_d_j$ - population density in CD j ;

a_pop_j - total number of population in CD j ;

$area_j$ - land area of CD j .

For 1991, the data for a_pop_j was derived by assigning provincial population estimated by Informetrica to CD j , proportional to the population of CD j in the total population of the corresponding province, according to 1991 Census. For the years from 1992 to 2010, this proportion was replaced by that based on CompuSearch's population projections at the CD level.

13.2.8 Vehicle Stock

Vehicle stock is defined as the total number of light duty vehicles in use before the modelling or forecasting year. The base data used to derive vehicle stock included the 1992 vehicle registration database for vehicles sold before 1992, and 1992-2010 new vehicle sales projections produced by the new vehicle sales model. The following methods were used to derive the vehicle stock data:

For vehicle stock before 1992: (1) light duty vehicles with the model years before 1978 (old vehicles), and presumably still surviving in 1992, were extrapolated graphically for each province, according to the vehicles after 1978 model years contained in the 1992 database (the database ignores the vehicles before 1978 model years); (2) The provincial total of old vehicles were assigned to each Census Division proportional to the vehicle stock of the CD in the province; and (3) a summary of these assigned vehicles and the vehicle registered in the 1992 database yielded vehicle stock at the Census Division level before 1992.

For vehicle stock after 1992: (1) the number of surviving vehicles of each model year of a CD was divided by a vehicle survival rate for the corresponding province (obtained from Energy Sector), yielding presumed new vehicle sales for each model year before 1992; (2) starting from 1992, the new light duty vehicle sales, projected by the new LDV sales model, were added into the new vehicle sales series; (3) surviving vehicles for each model year within the projection period were calculated according to the survival rates; and (4) vehicle stock before a forecasting year was derived by summarizing all the presumably surviving vehicles.

13.2.9 New Vehicle Affordability Indicator

This variable was constructed to indicate the average ability of a consumer to purchase and fuel a new vehicle. It is defined as:

$$inc_vc_j = hhld_inc_j / an_w_pfc_j \quad (\text{Equation 13-20})$$

where *inc_vc_j* - new vehicle affordability in CD *j*;
hhld_inc_j - average household income in CD *j*;
an_w_pfc_j - annual average vehicle purchase and fuel cost in CD *j*, weighted by vehicle class shares.

Similar to an_vpfs_i , $an_w_pfc_j$ consists of two components: annual new vehicle purchase cost $an_w_vpc_j$ and annual fuel cost $an_w_vfc_j$. Weighted by vehicle class mixes, $an_w_vpc_j$ and $an_w_vfc_j$ are defined respectively as:

$$an_w_vpc_j = \frac{1}{3} \sum_{i=1}^{13} (vprice_{ij} * Pepaij) \quad (\text{Equation 13-20})$$

$$an_w_vfc_j = \frac{fuel_price_j}{42.52} (vdt_pc_j * \sum_{i=1-9,11,12} \frac{Pepaij}{fe_i} + vdt_cg_j * \sum_{i=10,13-15} \frac{Pepaij}{fe_i})$$

(Equation 13-21)

where vdt_pc_j and vdt_cg_j are vehicle distance traveled for passenger cars and cargo trucks respectively. All other notions are the same as those used in the definition of relative vehicle purchasing and fueling cost (Equations 13-11 – 13-14).

13.2.10 Transit Vehicle Hours Serviced

This variable is defined as the total vehicle hours serviced including regular passenger service, auxiliary passenger service (such as school contracts) and non-revenue hours (such as road tests and training). It is one of the approximately 250 variables included in Canadian Urban Transit Statistics Database obtained from Canadian Urban Transit Association. The database contains a transit survey for over 90 municipalities for 1991. Similar data are also available for 1992-1994, but the survey units are not completely consistent with the 1991 database.

According to the correspondence between the municipalities named in the transit database and the Census Division names contained in the Census Database, the 1991 transit vehicle hours data was integrated with the Census Database, and used for modelling new vehicle sales for 1991. A comparison of the 1991 and 92-94 transit

databases revealed that transit service was fairly stable during these years, in terms of the vehicle hours serviced. Therefore, the 1991 data was used for the forecasting period as well, for both the service stability and the lack of appropriate data after 1991.

13.2.11 Other Variables

Numerous other variables have also been tested, and the data processed. For example, standard road density is defined as the length of standard roads divided by the area of a region. Standard roads refer to the roads at five levels represented in the provincial road map at 1:2M, produced in 1992 by NRCan (formerly known as Energy, Mines and Resources Canada). To derive the road density data, a digital standard road distribution file was obtained from GeoAccess Division. The standard roads, as well as their length, by Census Divisions were obtained by overlaying this map with a Census Division Boundary map, using the ArcInfo GIS. Another example is the test of a dummy variable representing urban and rural areas. Extensive tests have been performed to enhance the model specification by including these variables in the model in various ways. Most of these variables, however, have been eventually dropped from the models. It was found that the variable of geographical suitability had a comprehensive explanatory capacity. Such variables as population density, rural/urban difference and road network have probably been well represented in this indicator.

Chapter 14

Methodology for Model Building and Forecasting

Figure 14-1 illustrates the major processes performed in the modelling and forecasting of new LDV sales mixes. Spatial data integration and processing aims to obtain a spatial database ready for model estimation and forecasting. Spatial exploratory data analysis attempts to understand the spatial and thematic structures of the data. The models are estimated in the process of model fitting, which embraces a range of procedures aimed at ensuring the quality of models. The models are then verified according to available methods and existing knowledge, historical data and forecast. Based on the verified models, new LDV sales mixes are forecast on the assumption of business-as-usual as well as selected policy measures. The entire process is iterative, in an attempt to achieve a reliable model and forecast.

Figure 14-1: Primary methodology for modelling and forecasting new LDV market share and sales

The in-house integrated environment for spatial statistical analysis and visualization (IESSSAV) was used for the model development, complemented with a series of C programs written to facilitate the modelling and forecasting processes²⁴ (Zhang and Yu 1994). The main components of IESSAV include a spatial statistical package SpaceStat, a spatial data exploration and visualization package ArcView, a GIS ArcInfo, and a high-dimensional variable visualization package XGobi.

14.1 Spatial Data Integration

As stated earlier, Census Divisions (CD) are defined as the spatial units of observations for the construction of spatial samples. It is therefore essential that all the data sets involved, for both modelling and forecasting, consist of observations at this level of spatial aggregation. This condition, however, was not readily met, due to different data sources from which the data sets were obtained. For example, the 1992 CVIOC database is geographically referenced to postal code areas, while fuel price, provincial vehicle purchase tax, and standard road distributions are available by provinces. It was therefore necessary to convert, or integrate, these diverse data to the level of Census Divisions.

The most intensive effort made for data integration was the conversion of the vehicle census data from postal code areas into Census Divisions. The data came with three separate files, one for the counts of vehicles by type and by postal code areas with up to millions of records, one for the indexing of the count file via postal code, and one for vehicle descriptions with vehicle codes related to the count file. The count file was first aggregated into Census Divisions, via the postal code indexing file and a postal code-CD conversion file acquired from the company CompuSearch. The resulting file was then joined with the description file, which includes vehicle size classification, and numbers of vehicles by size class were further obtained within ArcView.

²⁴ Under the author's supervision, a research assistant carried out the following tasks for the modelling and forecasting processes: converting the vehicle census database from Postal Code Areas to Census Divisions; assisting in variable processing; performing business-as-usual forecast based on the models developed; and writing most of the C programs needed to facilitate the modelling and forecasting processes.

The integration of the Urban Transit Service database with other data in use also took special effort, since there was no common field which could link the municipalities in the database with Census Divisions directly, although in principle each municipality corresponds to one Census Division. A careful match between the municipalities and Census Division names was therefore conducted, and CD codes were assigned to corresponding municipalities for subsequent integration.

14.2 Spatial Exploratory Data Analysis

With approximately a hundred potential explanatory variables available for testing, exploratory data analysis became necessary for improving not only the understanding of data, but also the efficiency of model building. Three types of exploratory analysis were involved in the modelling process, namely correlation analysis (including spatial correlation analysis and non-linearity analysis), principal component analysis, and spatial heterogeneity analysis.

Spatial correlation analysis was performed between the predictor variables and predicted variables, and between all of the predictor variables. The exploration of the latter relationships was aimed at reducing the number of variables to be included in the models. First, SpaceStat was used to compute all the correlation coefficients, which gave a brief idea as to whether and how linear correlation existed between the variables. These coefficients, however, could not reveal such cases as outliers and non-linear relationships. A graphic method was therefore used for further exploration. Although ArcView provides a good tool for the generation of scatterplots, the bivariate combination of nearly a hundred variables make up to thousands of scatterplots, which could hardly be done in a reasonable time scale. An Avenue program (the scripting language of ArcView) was therefore written to automatically generate these plots. The correlation analysis revealed the major groups of variables related to the predictor variables, and the representativeness of some variables over other variables (mostly within the same variable group such as income).

The number of variables being tested had been greatly reduced after the correlation analysis. However, the variables remaining to be considered were still complex. The principal variables representing relatively independent dimensions in relation to the predicted variables were yet to be identified. A principal component analysis therefore followed. The resulting principal components as well as the loadings and scores provided good evidence for grouping the large number of variables. The dynamic, high dimension data visualization package XGobi was also used to explore the clusters of variables within the high dimension variable space. As a result, a small number of variables were identified to be the representative explanatory variables potentially useful for the models.

With assistance from maps, the scatterplots made for correlation analysis also served for the exploration of spatial heterogeneity. Details are described in Section 14.3.1.

14.3 Model fitting

With all the explanatory variables identified, spatial regression models were estimated using SpaceStat. Firstly, an Ordinary Least Square (OLS) procedure was run to obtain estimates for a standard regression model, along with an analysis of variance table and an array of model specification diagnostics. Various attempts were then made to improve the model, so that the spatial effects were eliminated (or taken into account), models were correctly specified, and a good measure of fit was achieved. The following issues were carefully dealt with in this process.

14.3.1 Dealing with Spatial Heterogeneity

The spatial effect of heterogeneity has been described in Section 12.2. Great effort was made to eliminate this effect in the models. The specification diagnostics provided by the standard regression run include three tests²⁵ for heteroskedasticity: two for specified

²⁵ The tests presented in the specification diagnostics are exclusively asymptotic in nature. They are considered to be reliable for the current case, given the large size sample (284 observations) used in this case.

forms of $h(z)$ (the heteroskedastic function, see Section 12.2.2) for normal and non-normal errors respectively, and one for unspecified form of heteroskedasticity (White test) where the square and cross products of the explanatory variables are used to define the form of $h(z)$. Given the lack of prior knowledge of the forms of heteroskedasticity in the current case of modelling, the White test was used during the model fitting. The elimination of the heteroskedastic problem was attempted through two approaches, the change of model specification and the use of heteroskedastic error models.

The use of heteroskedastic error models is relatively straight forward. However, model specification changes, which usually bring more significant model improvements than the error models, involve a great deal of analysis and testing. In general, two types of specification change can be made: separating the whole sample into a number of regions - the spatial regime approach dealing with structural instability; and replacing a coefficient with a function - the spatial expansion approach dealing with continuous parameter variation.

The Spatial Regime Approach

With regard to the spatial regime approach, three analyses were conducted, and corresponding methods used to deal with the problem. First, a residual map and a scatter plot between residuals and observation numbers were made, to identify regional differences in mean residuals. A region can be a province, a group of adjacent Census Divisions, or a group of Census Divisions with a same property (such as farming areas). Where mean residuals significantly differ from others, a regional dummy, which has a value of 1 for all the Census Divisions in that region, and a value of 0 for all other Census Divisions, can be used to adjust the constant for the region.

If the addition of such a dummy or dummies into the model could not resolve the problem of heteroskedasticity, a second analysis followed to re-examine the relationships between the predicting and the predicted variables, using the map and scatter plots produced for this purpose at the stage of exploratory data analysis. Regional dummies were created to separate the variables that exhibit different relationships with the

predictor variable in different regions. The model was then fit again to see the significance of the regionalized variables and the effect on heteroskedasticity

For example, Figure 14-2 illustrates the regional difference in the relationship between the percentage of population aged 30-44 and the market share of small vans. At first glance, it was confusing that the age group 30-44, which should be the major consumers of small vans, appears to be negatively correlated to the small van's market share. A spatial heterogeneity exploration searching the corresponding locations of observations in the map and the scatterplot, however, revealed that the relationship between these two variables was essentially positive. Within this correlation, however, a structural change occurred which separates Canada into two regions (termed regimes): the provinces of Eastern, Quebec and BC, and the four central provinces. Therefore, the variable of age group 30-44 was divided into two via a regional dummy for the two regions respectively. Subsequent model fitting resulted in corrected model specifications and improved measures of fit. Figure 14-3 shows another example of such an exploratory analysis. The correlation between fuel intensity and the market share of small utility trucks is obscured by a set of points on the bottom-right of the plot. This set of points is found to be the major farming areas, as shown on the bottom-right map. This analysis thus reveals that there is a high correlation between fuel intensity and the market share of small utility trucks, except for the farming area. A regional dummy variable would improve model specifications if the relationship is modelled.

If these methods were inadequate, model fitting proceeded with a third analysis, which examined the scatter plot between the residuals and the explanatory variables. Likewise, the explanatory variables that exhibit significant structural changes in correlation to the residuals were regionalized in order to eliminate the remaining heteroskedasticity. In the case where the relationships between the predicting and the predicted variables exhibited

Structural Variation between Two Regimes

Figure 14-2: Example of spatial regimes: two regimes are identified in the correlation between population age group 30-44 and the small van market share

Figure 14-3: Example of spatial regimes: two regimes are identified in the correlation between the market share of small utility trucks and the average new light vehicle fuel intensity

systematic structural instability (namely the same structural change occurs to all the predictor variables), a total switching regression was performed to obtain different models for different regimes.

The Spatial Expansion Approach

If the spatial regime approach could not adequately resolve the heteroskedastic or model mis-specification problem, a spatial expansion function was used to replace the coefficient of the variable that was expected to vary continuously with space. The expansion functions were mostly expressed in the form of a trend surface, at either the first or second order. In some cases, spatial expansion was performed with the constant of a model, rather than the coefficients of variables in the models.

Given that the observations we are dealing with are Census Divisions, which are not continuous over space, the variables used to construct a spatial trend are the x and y coordinates of the label points of all Census Divisions. In general, a label point is located in the centroid of a Census Division.

When both the spatial regime and spatial expansion approaches could not eliminate heteroskedasticity, a heteroskedastic error model was chosen from SpaceStat for model estimation. Different forms of such error models are available, as introduced in Section 12.2.2. A groupwise model, rather than a generic coefficient or random coefficient model, was mostly used for two reasons. First, the existence of regional difference was more evident than the causes of heteroskedasticity, which is needed in order to specify the heteroskedastic function. Second, the random coefficient error model was found often to result in non-positive definite variance problem, which failed the model estimation.

14.3.2 Dealing with Spatial Dependence

The specification diagnostics resulting from a standard regression procedure include various spatial dependence tests, four tests for error dependence and four for spatial lag dependence. In general, all the tests were taken into consideration in judging the

existence of spatial dependence. In the case where the tests generated different results, the one with stronger indication of spatial dependence was taken, since each of the tests is supposed to have the highest power for the case for which the test was designed.

In most cases, an ordinary least square run resulted in the specification diagnostics that suggested the coexistence of spatial error and spatial lag dependencies. SpaceStat, however, does not have the model specification that enables the consideration of both the spatial error and lag dependencies. To deal with the problem, the modelling process proceeded with a spatial lag model fitting first, with the recognition that spatial lag dependence exists with most of the predicted variable (as evidenced on the maps in Appendix 4). The weight matrix, which was generated based on ArcInfo, took the neighborhood form with rows standardized. In some cases, a spatial lag model estimation led to a significant spatial autoregressive and regressive model, with specification diagnostics showing insignificance of spatial error dependence. In other cases, however, the spatial lag variable appeared insignificant, and/or the error dependence persisted.

In the cases where spatial dependence persisted, model fitting generally proceeded with the addition of an error dependence term into the model, in order to deal with the problem of lag-error-dependence coexistence. Where specification diagnostics still suggested the existence of spatial dependence, a spatial exploratory analysis was performed, to examine the pattern of spatial dependence of the predicted variable as well as the residuals via the corresponding maps. Meanwhile, a reference was made to the scatter plot of observation numbers and the predicted variable, and to that between observation numbers and the residuals, respectively. If spatial dependence exists only in part of the regions, a regional spatial lag term or a regional spatial error term was added to the model, to improve the specification of the dependence terms.

14.3.3 Improving Goodness-of-fit

After the elimination of spatial effects, the measures of fit became reliable in terms of regression assumptions. For many of the models, however, these measures were not completely satisfying. Three methods were utilized to further improve the models.

First, scatter plots were made between the residuals and the explanatory variables used in the model, for the identification of non-linear relationships. For those explanatory variables whose scatter plots (with the residuals) exhibited a clear non-even distribution, corresponding transformations were performed with these variables, and the transformed variables were added into the model for testing the improvement of goodness of fit.

Second, scatter plots were also made between the residuals and some explanatory variables not included in the model, in order to add to the model more variables to further explain the residuals.

Finally, residual outliers were identified based on the outliers found by SpaceStat, and by the examination of residual distributions in both the residual map and the scatter plot of observation numbers and the residuals. To deal with outliers, positive and negative outlier dummies²⁶, created for the positive and negative outliers respectively, were included in the models for final model improvement.

Essentially, the inclusion of outlier dummies into a model is equivalent to the exclusion of these observations from the data sample. By either excluding the outlier observations or including the outlier dummies, the measures of fit become better indicators of the goodness of fit of the model. The difference is that the exclusion of them simply keeps outliers away from the estimation, while the inclusion of the outlier dummies forces the

²⁶ An outlier dummy is such a variable that has a value of 1 for identified outlier observations, and a value of 0 for all other observations

prediction for these outlier observations to better fit the observation values. As a result, the latter allows the outlier observations to be predicted while the former does not.

14.3.4 Special Treatment for Policy Variables

Policy variables, in particular relative vehicle purchase and fueling cost for each LDV size class for the sales mix models, must be included in the models, in order to enable the models to support a policy test. Great effort has been made to have these variables properly included. This involved the search for an optimal combination of the explanatory variables for a model, while ensuring that the policy variable was significant and had a correct sign. In the case where a policy variable could not contribute together with other theoretically important variable(s), an appropriate manipulation of these variables was performed, to allow for the inclusion of all the variables into the model. The construction of the variable of relative vehicle purchase and fueling cost is an example of this (c.f. Sections 12.4.3 and 13.2).

14.3.5 Other Issues

Sign of Coefficients

Any explanatory variable, when added into a model, was expected to have a positive or negative sign on the coefficient, according to general knowledge and the exploratory data analysis. This expectation, however, was not always met, due to model misspecifications. For the variables with small contributions to the model, the opposite sign generally led to the exclusion of the variable from the model. For those that have a large power of explanation in the model, the unexpected-sign problem often entailed many tests, in order to find an appropriate specification for the variable. Spatial heterogeneity analysis was another way to deal with the problem, as discussed in Section 14.3.1. Sometimes, non-linearity checks and the corresponding transformations were involved as well, in order to correct the misspecification.

Multicollinearity

In principle, the explanatory variables included in a regression model should be independent from each other. This independence, however, can hardly be found in the real world cases, including the current case of modelling. Principal components extracted from the relevant explanatory variables do have the ability to make up a set of explanatory variables that are independent from each other. The purpose of using vehicle class mix models in support of policy assessments, however, requires that policy variables be explicitly represented in the models, therefore prohibiting the use of principal components. To deal with this problem, a primary solution used in this modelling process was to reduce the correlation between the explanatory variables to a minimum, by stepwise testing the combination of different explanatory variables in a model while ensuring other good properties of the model.

Non-normal Residuals

The tests of most hypotheses and a large number of regression diagnostics are based on the assumption of normal distribution of residuals. A test of residual normality was therefore examined during the model fitting process, in order to ensure the validity of other statistical tests involved. It was found that, after the elimination of spatial effects and the improvement of goodness of fit, all the models resulted exclusively in errors with a normal distribution.

14.4 Model Validation

The ideal method for model validation is to verify the forecast (or backcasts) produced by the model using observational data. Such data, however, are unavailable by Census Division in the current case. The following alternatives were therefore used for model validation: confirmation of correct model specifications, selection of appropriate models, and verification of the models by comparing the forecast with common knowledge, aggregate historical data, and other aggregate forecasts.

14.4.1 Confirmation of Correct Model Specification

In general, the process of model fitting, as described earlier, should result in correct model specifications. The confirmation of this was performed in two ways. Firstly, the models were checked to ensure that the explanatory variables had the signs of coefficients as expected according to general knowledge. Secondly, a comparison between the test statistics Wald, LR and LM²⁷ was made for each model (Anselin 1995). In general, the magnitude of these statistics should satisfy the order:

$$\text{Wald} \geq \text{LR} \geq \text{LM}$$

Otherwise, there may be potential specification errors, such as non-normal error terms, non-linear relationships and poor choice of explanatory variables.

The checks showed that all the explanatory variables in the vehicle sales market share models have the signs as expected, and the magnitudes of Wald, LR and LM statistics for all the models follow the required sequence.

14.4.2 Model Selection

The model fitting process resulted in a number of models for each predicted variable. In general, a final model was selected according to the measures of fit, the stability of model coefficients, the availability of predicted data for the explanatory variables, and the systematic rationality of the explanatory variables for related models.

In standard econometrics, R^2 the coefficient of multiple determination, is provided for measuring the goodness-of-fit of a model, and the R^2 is directly linked to the F-test, which tests the overall significance of the model. In spatial econometrics, however, such R^2 becomes meaningless, since the estimation based on FGLS (Feasible Generalized Least Square) or ML (Maximum Likelihood) resulted in residuals with non-zero means,

which disable the standard decomposition of observed variance into explained and residual variance - the basis of R^2 . F-test becomes meaningless as well.

Therefore, the goodness-of-fit, in the selection of new vehicle market share and sales models, was measured by such alternatives as pseudo R^2 (e.g. the squared correlation between the observed and predicted variables, namely in-sample predictive ability), the maximized log-likelihood (L), and/or the Akaike Information Criterion (AIC) (Anselin 1988). An additional measure used in model comparison was the standard deviation of errors. To make this deviation relative to the observation values, an in-sample model predictability measure was defined as follows:

$$P = 100 * \frac{\bar{y} - \sigma}{\bar{y}} \quad (\text{Equation 14-1})$$

where P is the predictability measure, $\bar{y}$ the observed dependent variable, and σ the standard deviation of errors.

In general, even for the same dependent variable, an explanatory variable has different coefficients in different models. The stability of the coefficients, which is of vital importance for forecasting, was another criterion used in model selection. A coefficient was considered to be stable if different estimation methods resulted in similar coefficient values.

Another factor considered in model selection was the appropriate relationships between the market share models. Some models include other vehicle class market share as its explanatory variable(s). For example, the market share of large pickup trucks is an explanatory variable for both the models of subcompact and compact market share. The overall rationale for these relationships was analyzed in the model selection stage, and the models that best reflect this rationale were identified as the final models.

²⁷ Wald statistic for testing the significance of spatial lag term in the model; Likely Ratio (LR) statistic for testing on the spatial autoregressive coefficient; Lagrange Multiplier (LM) statistic for testing spatial lag dependence.

An additional criterion applied in the model selection process was the availability of projected data for the explanatory variables. Road density, for example, made significant contribution to the small utility market share. A model without this variable was selected since the projected data for road density is unavailable.

14.4.3 Model Verification via Forecast

After all the vehicle market share models were completed and a forecast produced, the final step of model validation was performed by comparing the projected trends of new LDV class shifts with existing knowledge, data and forecasts. In particular, a brief interview was conducted with the people working on the relevant policy area at the Energy Sector. For the period from 1991 to 1993/1995, the forecast aggregated into the national level was further compared with the historical data series presented by the Transportation Energy Use Division at the Energy Sector (TEUD 1996) and J.D. Power and Associates (Ballew 1996), respectively. For the period from 1996 to 2001, the forecast aggregated to the national level was compared with the J.D. Power's projection on the Canadian new vehicle sales market (Ballew 1996). Furthermore, the forecast of average new LDV fuel intensity at the national level was compared with NRCan's estimates (NRCan 1997), EEA's estimates (EEA 1999), and the VFEIS data (TEUD 1996).

A first comparison of vehicle market share, for example, showed that the forecast of different vehicle class market share from 1992 to 2010 was primarily as expected, except for the market share of midsize cars. For this class, the forecast suggested a trend towards sudden increase in 1993, followed by a gradual slight decrease, although overall there was an increase from 1991 to 2010. This class of market share, however, is expected to be significantly increasing, since the people born in the baby booming period will enter the age group in favor of this vehicle size in the next 15 years.

The mid-size class market share model, as well as the causes for the projected trend, was therefore closely examined. A model revision then followed, with the hope that the

forecast based on the revised model would be consistent to the general expectation. In the revised model, the relative vehicle cost compared to the average LDV cost has been replaced with that compared to the average passenger vehicle cost. This revised model seemed to have enlarged the power of age group in forecasting. The projected results, however, were mostly consistent with the original ones, indicating other changes brought into the model through the revision have balanced out the enlarged power of aging population in the model. Consequently, the model as well as the forecast was considered to be reliable, and to have revealed a trend which was covered by the dynamic interactions of different phenomena, such as aging population and increases of fuel price, vehicle price and fuel efficiency.

14.5 Forecasting

Forecast was first performed on the assumption of no additional policy intervention. New light duty vehicle market share and sales by Census Divisions were projected from 1992 to 2010, based on the estimated models and the projected data for the explanatory variables, which were obtained from different sources. This business-as-usual forecast was the focus of this forecasting process. More details are provided in the following sub-sections. With this CD-level projection available, the forecast of vehicle market share and sales at the provincial and national levels was derived. Average new LDV fuel intensity was then computed at all these levels of aggregation, based on the vehicle market share forecast and the estimated fuel efficiency technology improvements derived from the US DOE's forecast.

On the policy assumptions of gasoline tax increase, the new LDV market share by Census Divisions was then projected with respect to each assumed magnitude of gasoline tax increase for the year 2010. The same computation procedure as for the business-as-usual scenario was used to derive the average new LDV fuel intensity scenarios at the CD level. Each of these scenarios was further compared to that on the business-as-usual assumption, resulting in the potential effects of gasoline tax increase measures on new LDV fuel efficiency improvements.

14.5.1 Forecasting of New LDV Market share by Census Division

Figure 14-4 illustrates the process for forecasting new LDV market share by Census Division. Firstly, the projected data obtained for deriving the explanatory variables of the market share models are processed, according to the definitions of these variables (c.f. Section 13.2). The outputs are a number of files, each corresponding to a variable and including data for all the forecasting years. The second step of data processing aims to obtain an input data file for a particular year for a particular model. Some variables are regionalized, according to the model specifications and the regional dummy variables obtained from the fixed variable files. The two fixed variables files are output from SpaceStat, as part of the model outputs for the new LDV market share model and the previous year's market share model, respectively. Subsequently, the regionalized variables, non-regionalized variables, and the variables assumed to be constant for the forecasting period are merged to form an input data file for each forecasting year.

The third step, which can be conducted in parallel with the second one, substitutes the function of previous year's market share into the corresponding market share model (c.f. Section 13.2.1), resulting in a combined market share model ready for forecasting. With both the data and model ready, the market share by Census Divisions is computed at the fourth step. Some projections of the market share fed back into the input file for use in the projection of other class market share (c.f. Chapter 18). The steps 2 to 4 are repeated from 1992 to 2010, and from vehicle class 1 to class 13. A standardization process then follows, to adjust market share so that all the market share add up to 100% for each forecasting year.

The process of model validation via forecast comparison, as described in the last section, was a process of forecast verification. In addition, the forecast of aggregate market shares between passenger cars and light trucks at the national level was compared to the historical data presented in the Energy Outlook (NRCan 1997) for the year 1995, the latest historical data in the outlook table. As consistency to the Outlook is generally

Figure 14-4: Process of forecasting new LDV sales mix

required, the national level aggregate shares were calibrated to the 1995 data. The same calibration process can be performed for the provincial and Census Division level projections, but this is beyond the scope of this thesis.

For the gasoline tax increase scenarios, each assumed magnitude of gasoline tax increase was added to the projected fuel price, as shown on the first left column, with the same process used for the subsequent computation. The scenario forecast was performed only for the year 2010.

14.5.2 Forecasting of New LDV sales by Census Division

The process involved in forecasting new LDV vehicle sales by Census Divisions is illustrated in Figure 14-5. There are two main differences compared with that used for market share forecasting. First, the first step of data processing here utilized the forecast of new LDV market share, in the calculation of average annual vehicle purchase and fuel cost (see Section 13.2). Second, a relatively complex procedure was involved in calculating vehicle stock before the forecasting year (Sections 13.2.8 and 15.10). In addition, a logarithmic transformation was performed for all the variables, as required by the model, and an exponential transformation was applied to the resulting new LDV sales estimates to convert the measure back to sales numbers.

Figure 14-5: Process of new LDV sales forecasting

Chapter 15

New LDV Market Share and Sales Models

Based on the conceptual framework, methodology and processed data, thirteen new LDV vehicle market share models and one new LDV sales model have been developed. For the models of new LDV sales and the eight major vehicle class shares (subcompact, compact, midsize, large, small pickup, small van, small utility and large pickup), the measures of model fit range from 0.83 to 0.98, in terms of the squared correlation between the predicted and the observed. For the other 7 vehicle classes which altogether took up less than 5% in total light duty vehicle, the measures of fit are mostly range from 0.75 to 0.80, with one exception that drops to 0.63.

It should be noted that, with regard to the issues of environmental concerns in vehicle class choice, these models, and the exploratory analysis performed during the modelling process, have confirmed that the levels of education are not significantly correlated to vehicle market share. Population age does have significant correlation with the market share. The extent to which people at different ages incorporated environmental concerns into their vehicle purchase decisions, however, needs further exploration.

This section presents the estimated models, along with brief interpretations. The socio-economic and vehicle cost variables are present in descending order according to their relative contributions to the model. Each market share model resulted from the substitution of the previous year's market share function into the corresponding market share model (c.f. Sections 13.2.1). The original estimates for the market share models and the functions of the previous year's market share are presented in Appendix 3, with analysis of variance tables associated. All the model specifications use the following notations for the variables commonly presented in the models:

pepai - a vector of vehicle market share estimates of size class *i* for all Census Divisions (CDs);

tppx_y - a vector of percentage of population aged from *x* to *y*;

- a_hinc* - a vector of average household income;
- oc_x_tp* - a vector of percentage of occupation *x* in total occupation;
- anpfsi* - a vector of annual amount of savings in vehicle purchase and fuel cost by owning a new size class *i* vehicle compared to the average cost of new LDVs; also called relative vehicle purchase and fueling cost;
- wypepai* - a vector of spatial lag dependence term: spatial weight matrix multiplied by *pepai*;
- wrpepai* - a vector of spatial error dependence term: spatial weight matrix timed by residuals of the model;
- o_fi* - a vector of factors other than those included in the models that contribute to the model, normally including a constant and outlier dummy terms if applicable, and the component of the previous year's market share not explained by the current year's socio-economic and vehicle cost variables (c.f. Section 13.2.1), which presumably contains such factors as cultural difference and comprehensive geographical suitability for the vehicle class *i*.

15.1 The Market Share Model for Subcompact Cars

The market share model for subcompact cars was estimated using a groupwise spatial heteroskedastic error model, which takes into account the variation of error variance in different regions. The market share in total LDV vehicles are specified in the form of a combined spatial lag and error dependence model:

$$pepa3 = 0.90tpp25_44 + 0.014anpfs3 - 0.00011a_hinc - 0.21pepa13 \\ 0.16wypepa3 + 0.57wrpepa3 + o_f3$$

Model -Class 3

The squared correlation between the observed size class 3 market share (i.e. the 1991 class 3 market share) and the market share predicted by this model is 0.94, with the standard deviation of errors being 2.09. The in-sample predictability of the model is

therefore 91.23%, based on the error standard deviation and the 1991 mean market share of 23.85%.

As can be seen, the percentage of population aged from 25 to 44 and the annual amount of vehicle purchase and fuel savings by owning a subcompact car make positive contributions to this market share model. The variables negatively correlated with the market share are average household income and the market share of vehicle class 13 (large pick-up trucks). The significant negative correlation between class 3 and class 13, to a large extent, reflects the geographical suitability for different classes of vehicles. In general, the areas with more subcompacts and less large pickups tend to be urban areas; otherwise, they are more likely to be rural areas.

15.2 The Market Share Model for New Compact Cars

The market share model for new compact cars (i.e. size class 4), estimated using a groupwise heteroskedastic model as well, is specified as a spatial error dependence model:

$$pepa4 = 0.025anpfs4 + 0.32tpp25_44 - 0.000056a_hinc - 0.15pepa13 + 0.38wrpepa4 + o_f4$$

Model-Class 4

The model has a squared correlation of 0.84 and a standard deviation of errors of 1.75. Its predicatability amounts to 90.54%, given the mean market share of 18.50% of this class of vehicles in 1991.

The variables contributing to this market share model are almost the same as those to the class 3 model. The weights of various variables in the model, however, differ from those in Model 3. The largest portion of contribution to the market share is made by the amount of vehicle purchase and fuel savings by owning a compact car, while the percentage of population aged from 25 to 44 takes the second position. Average

household income is still negatively correlated to the market share, but its contribution is smaller than that in the class 3 share model. Similarly, the market share of class 4 are high in urban and low in rural, as evidenced by its negative correlation with class 13.

15.3 The Market Share Model for New Mid Size Cars

The market share for new midsize cars (size class 5) is determined by a spatial lag dependence model, with spatial groupwise heteroskedasticity taken into consideration:

$$\begin{aligned} pepa5 = & 0.21tp55_75 + 0.026anpfs5 + 0.000045a_hinc \\ & + 0.29wypepa5 + o_f5 \end{aligned} \quad \text{Model-Class 5}$$

The model results in a squared correlation of 0.84, and a standard deviation of errors of 1.31. With the mean value of class 5 market share of 14.33%, the model has a predictability of 90.88%.

In contrast with the compact and subcompact cars, the mid-size cars are most favored by older people aged from 55 to 75. This age group variable is also the largest contributor to this model. In terms of cost, the model reflects the general tendency that the less cost with this class of vehicle compared to other vehicles, the larger market share this class takes up. Unlike to the compact and subcompact cars, this vehicle class is positively correlated to household income. Spatial lag dependence is significant with this class, as evidenced by the presence of the spatial lag term.

15.4 The Market Share Model of New Large Size Cars

For new large size cars (size class 6), the market share is explained by a spatial error dependence model, with spatial heteroskedasticity taken into account as well:

$$\begin{aligned} pepa6 = & 0.10tp55_75 + 0.00091anpfs6 + 0.000019a_hinc - 0.023pepa3 \\ & + 0.072oc_fa_tp + 0.33wrpepa6 + o_f6 \end{aligned} \quad \text{Model-Class 6}$$

The model has a high squared correlation of 0.94. The standard deviation of errors is 0.73, which, compared to the 1991 mean market share, leads to a predictability of 86%.

The demographic and economic factors affecting the purchase of new large size cars, as well as their relative importance in the purchase decisions, are primarily the same as those for the mid-size cars. The only exception is for the percentage of farming occupation, which has a significant positive correlation only to the market share of large size cars. The spatial effects for this market share model are in the form of spatial error dependence and spatial heteroskedasticity.

15.5 The Market Share Model for New Small Pickup Trucks

The market share model for new small pickups (size class 10) is expressed as a spatial lag dependence form, with spatial regimes incorporated:

$$\begin{aligned} pepa10 = & 0.0049anpfs10_fo + 0.0037anpfs10_nfo + 0.11tpp55_75 \\ & 0.18oc_fo_tp - 0.00067a_pop_d + 0.15wyepa10 + rd72_145 + o_f10 \end{aligned}$$

Model-Class 10

The model results in a squared correlation of 0.87. Its predictability is 85%, based on the error standard deviation of 0.79 and the 1991 mean market share of 5.19.

A significant regional difference is present in the correlation between this market share and the amount of vehicle purchase and fuel savings by owning a small pickup. As evidenced in the model, the coefficient of this explanatory variable is significantly higher in forest areas (*anpfs10_fo*) than in non-forest areas (*anpfs10_nfo*). In addition, a significant regional difference exists in the constant between the Census Divisions 72-145 (large part of Quebec) and the other areas, which is represented by the regional dummy variable *rd72_145*. With all these regional differences explained, there is still

slight spatial heteroskedasticity remaining. A spatial heteroskedastic model was therefore used in the model estimation.

In general, the factors positively contributing to the market share of small pickups are the relative vehicle cost, percentage of population aged from 55-75, and percentage of people with forestry as an occupation. Population density has a negative contribution to the model, indicating that more small pickups are found in rural areas.

15.6 The Market Share Model for New Small Vans

Also estimated using the groupwise heteroskedastic error model, the market share model for new small vans (size class 11) takes the form of a spatial error model with spatial heterogeneity explicitly specified:

$$\begin{aligned} pepa11 = & 0.0083anpfs11 + 0.16tpp30_44_omsa + 0.11tpp30_44_eqb \\ & 0.000025a_hinc - 0.00000098x_lab_nbc - 0.0000026y_lab \\ & + 0.47wrpepa11 + o_f11 \end{aligned}$$

Model-Class 11

The model has a squared correlation of 0.86. The standard deviation of errors is 0.92, which, compared to the 1991 mean market share of 7.97, gives a model predictability measure of 88.5%.

Spatial heterogeneity is evident in the relationships between the market share and some of the explanatory variables. In general, the model suggests that population aged from 30 to 44 is the primary buyers of small vans; however, the importance of this variable in the decision of purchasing this class of vehicles varies with region. As can be observed from the model, this importance is mostly consistent within the provinces of Ontario, Manitoba, Saskatchewan, and Alberta, while a different level of importance is found for the other provinces.

Spatial dependence exists as well. It is found that a spatial trend surface, which is represented by the variables of x_{lab_nbc} and y_{lab} , provides a better specification than a spatial lag term for the dependence in the spatial distribution of this market share. This trend can also be interpreted as a spatial drift existing in the constant of the model (c.f. Sections 12.2.2 and 14.3.1). Overall, the market share of small vans in 1991 exhibited such a trend that the further east and north, the less the shares, except for the province of BC where the market share of small vans were low.

In terms of thematic variables, the cost of owning a small van compared to average passenger vehicle cost makes the largest contribution to the market share – the lower the cost, the more the shares. With positive correlation to the market share as well, the age group from 30 to 44 and household average income take the second and third place in contributions to the model respectively.

15.7 The Market Share Model for New Small Utilities

Based on the groupwise heteroskedastic error model as well, the market share model of new small utilities (size class 12) is specified in the form of a spatial lag model:

$$pepa12 = 0.14tpp25_44 + 0.000071a_hinc + 0.0064anpfs12 \\ 0.10pepa3 + 0.76wyp90e12 + o_f12$$

Model-Class 12

The squared correlation between the observed and the predicted by this model is 0.83. The standard deviation of errors is 1.17, which, in comparison with the 1991 mean market share of 6.6%, leads to a model predicatability of 82.2%.

The inclusion of the variable of $wyp90e12$ indicates that the spatial lag dependence in the 1991 market share of small utility trucks was totally covered in the previous year's shares of this class ($p90e12$; see Appendix 3), in which a significant spatial lag dependence existed. The thematic factors significantly relevant to the purchase of small utilities are

found to be percentage of population aged from 25 to 44, household income, and the amount of saving (or additional cost) incurred by owning this class of vehicle. All these variables are positively correlated to the market share, with the age group making the largest contribution.

In addition, it is found that the spatial distributions of the market share of this class in 1991 followed a significant spatial pattern, namely the more sparse the standard roads and the more fluctuation of terrain, the more this class of vehicles. A variable of standard road density was therefore used during the modelling process. Although it makes a significant negative contribution to the model, this variable was removed from the model due to the lack of predicted data.

A substitution of road density with population density was attempted in the model revision, but a more appropriate variable for the replacement was found to be the market share of subcompact cars, which has a significant negative correlation to the share of small utilities. It was also found that the relationship between household income and subcompacts and that between household income and small utilities were opposed to each other. The larger shares of small utilities are found in richer areas while those of subcompacts are in poorer areas. The significant contribution of *pepa3* to the *pepa12* model can thus be interpreted as follows: both the subcompacts and small utilities are favoured by young people; while in areas with poorer driving conditions and/or higher household income, small utilities are more favored, otherwise subcompacts are more popular.

15.8 The Market Share Model for New Large Pickup Trucks

The market share model for new large pickup trucks (size class 13), also estimated based on the groupwise error heteroskedastic model, is specified as a combined spatial lag and error model:

$$\begin{aligned} pepa13 = & 0.30oc_fa_tp + 0.0060anvfs13 - 0.000015a_hinc \\ & + 0.53oc_fo_tp + 0.00000052x_lab + 0.0000016y_lab \end{aligned}$$

$$+ 0.077wypepa13 + 0.50wrpepa13 + o_{f13} \quad \text{Model-Class 13}$$

The model results in a high squared correlation of 0.98, with all other pseudo R^2 's being around 0.97 (Appendix 3). Its standard deviation of errors is 1.30, which, in comparison with the 1991 mean market share of 14.22, leads to a model predictability measure of 90.9%,

The existence of spatial dependence in the market share of large pick-ups is evident from both the map of this market share and the model. It is represented by the spatial lag variable *wypepa13*, complemented with spatial error dependence variable *wrpepa13*. Moreover, a significant spatial trend surface as a function of *x_lab* and *y_lab* exists with the distribution of the market share. The socio-economic factor most relevant to this class of vehicles is found to be the occupation of farming. The amount of fuel cost saving by owning this class of vehicle as compared to the average, ranks the second in contributing to these market share (it should be noted that vehicle price cost saving is not significantly correlated to this vehicle class). A larger market share of this class is also found in areas with lower household income and/or with more forestry occupations.

15.9 The Market Share Models for Other LDV Classes

The extremely low market share of other LDV classes (altogether less than 5%), including two seaters (size class 1), minicompact (size class 2), all the three classes of wagons (size classes 7, 8, 9), standard pick-ups (size class 14), and standard vans (size class 15), made the model building rather difficult. They should be interpreted with caution, given the measures of fit they have reached. They are considered as acceptable because of their minor importance in the vehicle market. Estimated using the groupwise heteroskedastic error model as well, these models are specified as follows:

$$pepa1 = 0.00018anpfs1 + 0.000010a_hinc + 0.0061tpp55_75 \\ + 0.003pepa3 - 0.004loc_fa_tp + 0.30wypepa1 + o_{f1}$$

Model-Class 1

$$pepa2 = 0.000055a_hinc + 0.00024anpfs2 + 0.40wypepa2 + o_f2$$

Model-Class 2

$$pepa789 = 0.000021a_hinc + 0.00038anpfs789 + 0.042tpp65_75 \\ + 0.016tpp65_75_npr - 0.020oc_fa_tp + 0.20wypepa789 + o_f789$$

Model-Class 789

$$pepa14 = 0.0000042a_hinc + 0.00013anpfs14 + 0.32wyp90e14 + o_f14$$

Model-Class 14

$$pepa15 = 0.0000039a_hinc + 0.0065oc_fa_tp + 0.00021anpfs15 + o_f15$$

Model-Class 15

The squared correlation coefficients of these models are 0.75, 0.63, 0.79, 0.79 and 0.95, with respect to the models subsequently. Accordingly, the model predictabilities are 66.7%, 62.0%, 90.6%, 71.6% and 60.5%, respectively. It should be noted that the high squared correlation of 0.95 for the class 15 model merits caution in interpretation, due to the remaining spatial effects as shown in the model estimates in Appendix 3.

All the first four models are specified as spatial lag models, indicating the significance of autocorrelation in the spatial distributions of these classes of vehicles. As can be observed, household income and the cost of owning the vehicle compared to the average cost are the two largest contributors to the models, except for *pepa15* for which the leading contributors are household income and the occupation of farming. In terms of population ages, the models suggest that people aged from 55 to 75 are more likely to own two seaters, while those aged from 65 to 75 are more likely to purchase wagons. The contributions of age groups to the wagon classes, though, vary with two regions: larger in the prairies regions and smaller in other areas. Also, these two classes of vehicles take larger market share in non-farming areas, in contrast to the standard vans which are more found in farming areas.

15.10 New LDV Sales Model

For the new LDV sales model, a ln transformation was applied to both the dependent and each of the independent variables. This transformation has greatly reduced the discrepancy of the data values, and has thus led to a significant reduction of the standard deviation of errors. Resulting from ordinary square estimations, this model takes the form of spatial regime model, with spatial error dependence incorporated into the model:

$$\begin{aligned} \ln_nldvs = & -3.41 + 0.98\ln_vs_east + 0.55\ln_inc2vc_east \\ & + 0.85\ln_vs_neast + 0.11\ln_ahoh_neast + 0.69\ln_inc2vc_neast \\ & 0.0063\ln_vhs_neast + wr_ln_nldvs \end{aligned}$$

Model-sales

where $\ln_nldvs$ - a vector of estimates of ln of new LDV sales for all CDs;
 $\ln_vs_east$ - a vector of ln of vehicle stock for eastern CDs;
 $\ln_inc2vc_east$ - a vector of ln of vehicle affordability indicator (i.e. the ratio of average household income to vehicle purchase and fueling cost) for eastern CDs;
 $\ln_vs_neast$ - a vector of ln of vehicle stock for all non-eastern CDs;
 $\ln_inc2vc_neast$ - a vector of ln of vehicle affordability indicator for non-eastern CDs;
 $\ln_vhs_neast$ - a vector of ln of transit vehicle hours serviced for non-eastern areas; and
 wr_ln_nldvs - a vector of spatial error autoregressive term added to the model.

The model has a squared correlation of 0.98, and a predictability of 88.1%. Unlike the other spatial error dependence models in which the error dependence variable participated in the final model estimation, the estimation of new sales model was performed based on OLS estimation first, and the error dependence term, estimated separately from the main model, was then added into the model (this way yields better

results in this case). The measures of fit present in the OLS ANOVA table is therefore mostly valid because of the removal of spatial effects by the added error dependence term.

As shown in the model specifications, the coefficients for all the thematic variables differ from the Eastern to the non-Eastern areas, reflecting a systematic instability of relationships between new LDV sales and the relevant thematic variables. The dominant variable for both the regions is found to be vehicle stock, namely larger stock generally suggests the demand for more new vehicles. Number of household is conceivably a factor affecting new vehicle sales. This variable, however, is significant for the non-Eastern areas, but insignificant for the Eastern areas. Given that vehicle stock has a high correlation with household numbers in the previous year, the insignificance of this variable in the Eastern provinces may suggest the relative stability of household numbers as well as new vehicle sales in these areas.

As expected, the variable of vehicle affordability, represented as the ratio of household income to average vehicle purchase and fuel cost, is positively contributing to the model for both the Eastern and non-Eastern areas. In addition, transit vehicle hours serviced, as an indicator of public transit accessibility, is found to be negatively correlated to the new vehicle sales. This correlation is significant for the non-Eastern provinces, but insignificant for the Eastern provinces.

Given the high measures of fit, the forecast of new LDV sales produced by this model is considered to be reliable for use as weights in aggregating new LDV class shares from the CD level to the provincial and national levels. To make the model capable of forecasting new LDV sales, however, one more variable needs to be included in the model, namely the number of scrapped vehicles in the predicting year.

Chapter 16

A Business-as-usual Forecast of New LDV Market share, Sales, and Average Fuel Intensity

New LDV market share by Census Division have been projected from 1992 to 2010, on the assumption that there will be no significant changes in the factors affecting consumers' vehicle class choice over the forecasting period. This forecast reflects the trend of new LDV class shifts attributable to socio-economic factors, vehicle pricing, vehicle fuel efficiency technology improvements, and geographical suitability. Based on this forecast and the forecast of new LDV sales by Census Divisions, the market share at the provincial and national levels has been derived, and average new light duty vehicle fuel intensity has been estimated at all these levels of geography. This chapter presents the major results with a brief analysis according to the data used for the projection. To make the analysis easier, the forecast aggregated to the national level is presented first, followed by that at the disaggregate levels.

16.1 Forecast of New LDV Sales Shifts and Average Fuel Intensity for Canada

Chart 1 presents the forecast of new LDV class shifts from 1992 to 2010 at the national level, with 1991 sales mix included for reference. The forecast of average new LDV fuel intensity for Canada as well as large provinces is presented in Chart 2. The fuel intensity estimates for 1991-1993 were derived based on the VFEIS database by the Transportation Energy Use Division, and those for 1994-2010 were projected through this case study.

Overall, the charts show that the changes in new LDV class mix would be moderate in this forecasting period; so would the average fuel intensity improvement, which would see a primarily constant trend till 2000, and a significant rate of improvement afterwards.

Chart 2: New LDV fuel intensity forecast: Canada and selected provinces

In particular, the market share of subcompacts and large pickup trucks would decrease by 8.5% and 1.2% respectively, from 1991 to 2010. Of this decreased portions, over 3% would be picked up by small utilities, nearly 2% by midsize cars, around 1.5% by small vans and small pickup trucks respectively, and over 1% by compacts, wagons, large and 2-seater cars altogether. While it is difficult to find out how the market share would switch from each other, the difference between the increase of small pickups and the decrease in large pickups does suggest that the switch would take place not only within passenger cars or cargo trucks, but also between them. For example, users who used to buy large pickup trucks may switch to compact cars. This is likely to happen in the prairie provinces where farming as an occupation with a high demand for large pickup truck is projected to decrease significantly in the following decade.

With regard to vehicle fuel intensity, the effect of the market share switch would differ between passenger cars and cargo trucks. While vehicle fuel efficiency technology would improve for all vehicle classes, the shifts from small to large cars would, to a large extent, level off this effect on passenger vehicles. This effect, however, would be enhanced on light trucks, because of the likely shifts from large to small pickup trucks. Consequently, there would be a moderate improvement (by about 5.9%) of average new LDV fuel intensity from 1991 to 2010 in Canada.

In terms of changing rates, over the forecasting period, the market share of small utility trucks would increase by 49.6%, small pickups by 41.1%, small vans by 15.9%, mid-cars by 12.0%, large cars by 5.7%, and compacts 2.4%. In contrast, subcompacts would decrease by 32%, and large pickups by 13.4%.

A close examination of the model performance and the projected data used in the forecasting reveals that, in general, the factors dominating the class shifts are the changes in relative vehicle cost of different vehicle classes and population age. Chart 3 shows the projections of the relative vehicle purchase and fueling cost of the major vehicle classes

Chart 3: Projected vehicle purchase and fueling savings (national means based on CD)

for the forecasting period (national means of Census Division based measures). The projections decomposed into relative vehicle purchase saving and fueling saving are

presented in Charts 4 and 5, respectively. Chart 6 shows the mean changes in the percentage of population of the two relevant age groups. Income and occupation play a dominant role in the shifts of such vehicle classes as small utilities and large pickups. Chart 7 presents their mean projections over the forecasting period.

Chart 4: Projected vehicle purchase savings (national means based on Census Division)

Chart 5: Projected vehicle fueling savings (national means based on Census Division)

By examining the particular contributions of selected variables in the market share forecast (Table 16-1), it is found that the significant decrease of the subcompact share is caused by a significant decrease in the age group 25-44 which would take place from 1991 to 2010. Although subcompacts would still have the largest cost advantage in passenger cars, the increase of this advantage would be overwhelmed by the decrease of

Table 16-1: Magnitudes of contributions to subcompact market share by thematic variables

Year	Tpp25-44	Anpfs3	A_hinc	Pepa13
1991	28.81	26.88		
1993	28.20	24.79	-5.70	-2.97
1995	27.60	25.75	-5.82	-2.92
1996	27.35	25.57		
2010	24.72	27.41	-7.99	-2.66

Chart 6: Projected percentages of population aged from 25-44 and from 55-74 (national means based on Census Division)

Chart 7: Projected household average income (national mean based on Census Division)

potential buyers as well as the increase in household income. Table 16-2 also reveals the reason for the oscillating change in subcompact market share during the period 1991-

1996, namely the oscillation of the relative vehicle purchase and fuel cost of subcompact cars over this period.

The significant decrease of age group 25-44 causes the decrease in the demand for compact cars as well. However, as shown in Chart 2, this effect would be leveled off by the significant increase in the cost savings of owning compact cars, and the significant decrease in those of midsize and large cars, which may lead to part of the increasing population aged 55-75 purchasing compacts rather than midsize or large cars.

The possible shifts from midsize and large cars to compacts can also be observed from Tables 16-2 and 16-3. The significant increase in population aged 55-75 would significantly increase the market share of midsize and large cars. For midsize cars, however, this increase, along with the increasing household income, will to a certain extent, be balanced off by the overall decrease of cost savings for this class of vehicles. Likewise, for large cars, the expansion of the older age group 55-75, and the potential shift to large cars from subcompacts, would be counteracted by the overall increase in the relative vehicle cost of owning a large car, and the significant decrease in the percentage of farming as an occupation. As a result, there would be increasing older buyers of midsize

Table 16-2: Magnitudes of contributions to midsize car market share by thematic variables

Year	Pepa5	Anvpfs5	TPP55-75	A-hinc
1992	16.99	21.10	5.77	2.92
1993	20.27	24.40	5.80	2.95
1995	19.10	23.00	5.90	2.99
1998	18.70	22.30	6.10	3.10
2010	17.61	18.80	7.50	4.10

Table 16-3: Magnitudes of contributions to large car market share by thematic variables

Year	Pepa6	Anvpfs6	TPP55-75	A-hinc	Oc-fa-tp	Pepa3
1992	5.26	-1.80	2.20	1.02	0.47	-0.52
1993	5.44	-1.67	2.22	1.44	0.46	-0.48
1995	5.41	-1.75	2.27	1.05	0.45	-0.49
2010	5.90	-2.27	2.87	1.03	0.40	-0.42

and large cars, but compact cars would be an alternative for those older people who cannot afford the cost. The sudden increase in the cost savings of owning a midsize or large car around 1993 also explains the significant increase in the market share of these cars during this period (as shown in Chart 1).

The decrease in young age groups has negative effects on the market share of small vans and small utilities as well (Tables 16-4 and 16-5). For small vans, however, this

Table 16-4: Magnitudes of contributions to small van market share by thematic variables

Year	Anvpfs11	P3044omsa	P3044eqbc	A-hinc
1992	5.67	3.71	2.63	1.32
2010	7.15	3.26	2.20	1.85

Table 16-5: Magnitudes of contributions to small utility market share by thematic variables

Year	A_hinc	TPP25-44	Anpfs12	Pepa3
1992	3.79	4.53	-2.38	-2.17
2010	5.32	3.92	-2.01	-1.74

effect would be balanced by the significant increase in relative savings of owning a van, along with the increase in household income. The small van market share would therefore grow continually. For the small utility class, the market share is particularly sensitive to household income, which indicates that small utilities are of particular interest in high income areas. This sensitivity makes the income increase from 1991 to 2010 a significant contributor in the market share increase. This contribution, along with the decrease in both the higher cost of owning a small utility vehicle and the contrasting market share of subcompacts, would balance the negative age effect, making the growth rate of small utility market share the largest of all the LDV classes.

These analyses reveal that the projected magnitudes of sales mix shifts depend on two factors: the projected magnitudes of changes in the variables of demography, economy, vehicle price and vehicle fuel efficiency technology improvements; and the dynamic interactions between these variables. It is the ability of tracking the likely changes in these factors, as well as the dynamic interactions among these factors, that makes the new LDV sales mix models a powerful tool in support of related policy-making.

16.2 New LDV Sales Shifts and Average Fuel Intensity by Province

Charts 8 to 14 illustrate the new LDV market share as well as their shifts at the provincial level (the Atlantic provinces are grouped into one region). Changes in average vehicle fuel intensity in major provinces are included in Chart 2. It is evident that significant regional differences exist in both vehicle class shares and average fuel intensity, and their rates of change.

In the Atlantic provinces (Chart 8), there would be more subcompacts, compacts and midsize cars and less large cars and small vans, as there were in 1991. Compared to the national averages (Chart 1), the market share of subcompacts would shift more to compacts and midsize cars in these areas, although small utilities and small vans would see increases as well. The average new LDV fuel intensity was close to Canada's average in 1991, and would be so throughout the forecasting period, with a rate of improvement of approximately 6.5%.

Compared to the national averages, the market share of subcompacts and compacts in Quebec (Chart 9) was much larger in 1991, and should continue to be so throughout the forecasting period, while those of large cars, small utilities, and pickup trucks was, and should be, much smaller. Although there would be significant shifts of market share from subcompacts to other classes, Quebec would be the only province where subcompacts would still enjoy the largest market in 2010. Thus, as was the case in 1991, the leading position of average new LDV fuel intensity in Quebec would keep steady throughout the forecasting period, with an approximate rate of improvement of 6.2%.

Chart 8

Chart 9

Given the large portion of sales Ontario takes, the class mix shifts in Ontario (Chart 10) have the largest resemblance to the national averages. This province, overall, would have larger market share of midsize cars, large cars, two-seaters and small vans, and less subcompacts and pickup trucks. The shares of compacts and small utilities would be equivalent to the national averages. As a result, Ontario's average fuel intensity, as well as the rate of fuel intensity improvement (6.0%), would be the closest to the national average.

Chart 10

The market share of midsize and large cars in Manitoba (Chart 11) would be higher than the national averages and equivalent to those in Ontario. Relative to the national averages, Manitoba would see larger shares of pickup trucks and smaller shares of subcompacts and small utilities. In addition, there would be significantly more shares shifted into compacts in this province than the national average. While there would be improvement as well, the average fuel intensity in this province would be lower than the national average, as was the case in 1991, with a rate of improvement of approximately 6.3%.

Chart 11

The sales mix shifts in Saskatchewan (Chart 12) exhibit a unique pattern: the market share of passenger cars as a whole is likely to increase, while those of large pickups would decrease greatly. This would be due to the likely decrease in farming as an occupation, which plays the largest role in determining the market share of large pickups. Similar to Manitoba, this province would see a significant increase in compacts as well. As a result, while its average fuel intensity was, and would be, lower than the national average (only higher than Alberta), Saskatchewan would see the largest rate of fuel efficiency improvement (by 8.7%) of all provinces.

Alberta would be the province with the largest decrease in subcompact market share (Chart 13). While large pickups, which take up the largest vehicle market share in this province, would see a decrease over the forecasting period, the rate of decrease would be much lower than that for subcompacts. These characteristics would cause this province to have the lowest average fuel intensity, as was the case in 1991, as well as the lowest rate of fuel intensity improvement (by 5.4 %) in the forecasting period.

Chart 12

Chart 13

Of all the provinces, BC (Chart 14) would have the largest market share of small utilities and the smallest market share of midsize and large cars, as was the case in 1991. Also, as was in 1991, the largest market share of two-seaters would be found in BC, although the share is small *per se*. The average fuel intensity in this province would be the highest among the four Western provinces, but lower than the national average. Similar to the Atlantic provinces, the rate of fuel intensity improvement in BC would be approximately 6.5% from 1991 to 2010.

Chart 14

16.3 Forecast of New LDV Sales Shifts and Average Fuel Intensity by Census Division

The business-as-usual forecast for new LDV sales mix was produced at the Census Division level, based on the estimated sales mix models. Four sets of maps, as shown in Maps 1-20, have been created for major vehicle classes, to demonstrate the spatial distributions of new LDV market share as well as their likely changes in the near future. The first set (Maps 1-5) includes five maps created based on the 1992 Canadian Vehicles

in Operation Census database, which was merged with fuel consumption ratings and vehicle size class information by the Transportation Energy Use Division of the Energy Sector. They represent the market share of major 1991 model-year new LDV classes, including subcompacts, compacts, midsize cars, small vans and small utility trucks. The second set (Maps 6-10) presents the forecast of market share for 2010 for the same vehicle classes. The changes in the market share for these classes from 1991 to 2010 are presented in the third set (Maps 11-15). The last set (Maps 16-18) includes average new LDV fuel intensity maps for 1991 (historical), 2010 (business-as-usual forecast), and the likely changes from 1991 to 2010.

In relation to the areas of policy interest, the spatial patterns are obvious, as exemplified by the selected major vehicle classes. For the Windsor-Quebec Corridor, the market share of subcompact, compact and midsize cars were particularly high in 1991, while the small utility share was low. The market share of small van shows a clear spatial pattern: the more south-west, the higher market share. Assuming no additional policy intervention, over the forecasting period, the Corridor would see significant, but average compared to other regions, reductions of subcompact market share in most areas. Changes in the market share of compact and midsize cars would be minor, with some areas increasing and some decreasing. The market share of small vans would increase significantly. The most significant growth, however, would take place in small utility vehicle sales. Consequently, in 2010, the market share of subcompacts in the Corridor would become average for Ontario, but still keep high for Quebec. The compact market share would be high overall, and among the highest in Quebec. The market share of midsize cars and small van would be high as well, especially in the south-west. Owing to their low bases, the market share of small utility vehicles, despite of large increasing rate, would remain low to average, except for the Greater Toronto Metropolitan area which would be among the areas to have the highest small utility share. Thus, in terms of average new LDV fuel intensity, the Corridor had low fuel intensity in 1991. There would be low to average improvements in the intensity in the forecasting period, assuming no additional policy intervention. As a result, this area would have average to low fuel intensity in 2010, with its Quebec section remaining the lowest in Canada.

Market Share of New Subcompact Cars - 1991

Subcompact Car Share (%)

Data Source: Canadian Vehicle In Operation Census Database
by DeRosiers Automotive Consultants, augmented with fuel
efficiency and vehicle size class by Natural Resources Canada

Market Share of New Compact Cars - 1991

Compact Car Share (%)

Data Source: Canadian Vehicle in Operation Census Database by DesRochers Automotive Consultants, augmented with fuel efficiency and vehicle size class by Natural Resources Canada

Market Share of New Midsize Cars **- 1991**

Midsize Car Share (%)

Data Source: Canadian Vehicle in Operation Census Database
by DesRosiers Automotive Consultants, augmented with fuel
efficiency and vehicle size class by Natural Resources Canada

Market Share of New Small Vans - 1991

Small Van Share (%)

Data Source: Canadian Vehicle In Operation Census Database
by DeRoosiers Automotive Consultants, augmented with fuel
efficiency and vehicle size class by Natural Resources Canada

Market Share of New Small Utility Vehicles - 1991

Data Source: Canadian Vehicle in Operation Census Database
by DesRoisiers Automotive Consultants, augmented with fuel
efficiency and vehicle size class by Natural Resources Canada

- 2010

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Forecast of New Compact Car Market Share - 2010

Projected Compact Car Share (%)

Forecast of New Midsize Car Market Share - 2010

Projected Midsize Car Share (%)

Forecast of New Small Van Market Share - 2010

Projected Small Van Share (%)

Forecast of New Small Utility Vehicle Market Share - 2010

Projected Small Utility Vehicle Share (%)

Forecast of New Subcompact Car Market Share Changes: 1991 - 2010

Change in New Subcompact Car Share (%)

Forecast of New Compact Car Market Share Changes: 1991 - 2010

Change in Compact Car Market Share (%)

Forecast of New Midsize Car Market Share Changes: 1991 - 2010

Change in Midsize Car Market Share (%)

Forecast of New Small Van Market Share Changes: 1991 - 2010

Change in Small Van Market Share (%)

Forecast of New Small Utility Vehicle Market Share Changes: 1991 - 2010

Change in Small Utility
Vehicle Market Share (%)

Average New Light Duty Vehicle Fuel Intensity -1991

Average Fuel Intensity Ltr/100km

Data Source: Canadian Vehicle in Operation Census Database by DesRochers Automotive Consultants, augmented with fuel efficiency and vehicle size class by Natural Resources Canada

Forecast of Average New Light Duty Vehicle Fuel Intensity - 2010

Average Fuel Intensity Ltr/100km

Forecast of Average New Light Duty Vehicle Fuel Intensity Improvement: 1991 - 2010

Fuel Intensity Improvement (%)

The lower mainland BC area had a high market share of subcompacts in 1991 as well. In contrast to the Corridor area, however, this area had high market share of small utilities, and low market share of compact and midsize cars. The market share of small vans are on average, close to the Quebec section of the Windsor-Quebec Corridor. Without additional policy intervention, decreases in the subcompact market share would take place in this area as well, at a rate similar to the Corridor area over the forecasting period. Changes in compacts and small van market share would be similar to the Corridor area as well – minor for compacts and significant for small vans. Unlike the Corridor area, the market share of midsize cars would increase in this area. The small utility market share would increase as well, but at a rate lower than the Corridor area. As a result, in 2010, the market share in this area would be average for compact cars, and above average for subcompact cars and small vans. The market share of small utilities will remain high compared to other areas, although the rate of increase would be relatively low. Likewise, the market share of midsize cars would still remain low compared to other areas, although the rate of increase would be high. In terms of average fuel intensity, this area was average in 1991, would improve at low-to-average rates over the forecasting period, and remain average in 2010, without additional policy intervention.

The new LDV sales mix models, and the projected data for the explanatory variables used in forecasting, can be further used to identify the reasons for the likely changes. To understand why the growth of small utility market share in the Great Toronto area would be among the largest, for example, the small utility vehicle market share model can be used to identify the major variables that drive the changes, namely the population group aged from 25–44, average household income, and the higher cost of owning a small utility vehicle. The projected data for these variables can then be examined to identify the source of the significant increase. Conceivably, there is a large potential for using the models, data, and visualization techniques in support of policy design. A detailed analysis of this potential is beyond the scope of this research.

Also to serve the interest of policy analysis, the forecast of new LDV sales mixes for large urban centres, namely Montreal, Toronto, and Vancouver, is presented in Charts 15-17. A comparison between the three urban centres shows: (1) the market share of subcompacts and compacts in Montreal would be approximately 13% higher than in Toronto, and 17% higher than in Vancouver; (2) the shares of midsize and large cars

would be the largest in Ontario and the lowest in Vancouver; (3) the small van market share would be equivalent in Toronto and Vancouver, but smaller in Montreal; (4) for small utilities, Vancouver would have the largest share, Toronto second, and Montreal the smallest; and (5) Vancouver would also see more pickup trucks, which would take very small share in both Montreal and Ontario. In addition, among these centres, the largest share of two-seater would be found in Vancouver, and large vans in Ontario. The shares of wagons are primarily equivalent in all these urban centres. In terms of the rate of class shifts, Toronto exhibits slightly more significant shifts, while the other two would be primarily equivalent and more constant.

Chart 15

Chart 16

Chart 17

16.4 Forecast Verification

Efforts have been made to verify the forecast of new LDV sales mix shift, using existing knowledge, historical data, and forecast. As all the references that can be used for comparison are at the national level, the verification has been performed only at this level.

First, the forecast was compared with common knowledge obtained from the people working on the transportation energy policy domain within the Energy Sector. It is found that the decrease in the subcompact market share is commonly expected. The increases in the market share of midsize cars, large cars, small vans and small utilities fall within the common expectation as well. There are, however, different opinions regarding the trend for the compact market share. Interestingly, this difference is well explained by the forecast, which suggests that the compact share would be increasing overall, but the rate of increase would be insignificant.

A second verification was performed by comparing the forecast with observational data. Unfortunately, such observational data are very limited. Although there are abundant Vehicle in Operation Census performed after 1991 Census (which was used in the modelling process), the data base does not have vehicle size class and fuel efficiency rating, which makes the comparison between the forecast and the observations impossible. Two historical series of new LDV vehicle market share, however, were found available for the period 1991-1993: one from the VFEIS database (see Appendix 1), and the other by J.D. Power and Associates (Ballew 1996). Table 16-6 illustrates the projected changes in the market share of the major vehicle classes. Small cars in J.D. Power's segmentation roughly correspond to minicompact, subcompact and compact cars in the size classification used in this case study. Van, sport utility and pickup trucks each includes both large and small ones. The line symbols mainly represent five levels of change: very significant increase (↗), significant increase (↖), no significant change (→), significant decrease (↘), and very significant decrease (↙).

As can be observed from the table, more consistencies are found between this forecast and J.D. Power's historical data. The projected sudden drop from 1991 to 1993 in the subcompact cars closely fits this historical data series. The projected trends for van, sport utility vehicles and pickup trucks are consistent with the trends exhibited in this data series as well. For large cars, however, the forecast is consistent to the VFEIS data. Sport utility is the only field in which both the historical data and the forecast display the same level of change.

Table 16-6: Comparing this forecast with historical data: market share changes 1991-1993

Source	Small car	Midsize car	Large car	Van	Sport Utility	Pickup
VFEIS data	^	v	—	^	—	—
J.D. Power's data	\	—	\	/	/	—
This forecast	\	/	—	/	/	—

Table 16-7: Comparing this forecast with J.D. Power's forecast: market share trends 1996-2001

Source	Small car	Midsize car	Large car	Van	Sport utility	Pickup
J.D. Power's forecast	—	—	/	—	/	—
This forecast	\	—	/	/	/	—

A third comparison was made between this forecast and the J.D. Power's forecast (Ballew 1996) for the overlapping period from 1996 to 2001. Table 16-7 illustrates these forecasts in the same way as Table 16-6. As can be seen from this table, both forecasts suggest that there would be a significant increase in the market share of utility trucks; a relatively significant increase in large cars (luxury cars); and no significant change in the market share of midsize cars and pickup trucks. The major differences between the two forecasts are for small cars and vans. J.D. Power's forecast suggests that small cars would primarily keep their current share, while the van market share would, to a small extent, decrease from 1996 to 2001. The forecast produced in this research, however, suggests that there would be a significant decrease in the market share of small cars, and

a slight increase in that of vans. Despite these differences, both the forecasts suggest the trend that the vehicle market would see more affluent, older, better educated and more mobile buyers; this shift favors small utility vehicles and luxury cars (Ballew 1996).

Furthermore, the forecast of aggregate passenger car sales shares v.s. cargo trucks are compared to the recorded data (from 1992 to 1995) and a baseline forecast (from 1996 to 2010), as presented in NRCan's Energy Outlook (1997). The two data series show the same trend: a significant shift from cars to cargo trucks in the early 1990's, and a small shift afterwards. The main difference lies between the magnitude of the early 1990's shift recorded in the data (approximately 15%) vs. the forecast through this study (approximately 5%). A 15% shift in five years as recorded may best be ascribed to fashions or the appearance of new vehicle models, which can hardly be projected by any models (c.f. Section 16.5), including the models developed through this study. The significant shift that this forecast suggests is mainly due to the drop of the relative price advantage of subcompact cars in that period, as shown in Table 16-2 (Section 16.1).

On the other hand, the primary consistency between this forecast and the Outlook in the shift from cars to light trucks after the middle of the 90's, seems to be a coincidence. The reason is that the rising income in the coming decade would cause a shift towards light trucks, but changes in many other factors, such as an aging population, vehicle price increase and occupation switch, tend to drag the shift back to passenger cars, resulting in a moderate shift from cars to light trucks in this period. These changes are represented in this forecast, but not in the projection of the Outlook. For the Outlook projection, income and fuel price are the driving variables for the shift. Fuel price, therefore, must have played an important role in this projection, to balance the shift to be caused by rising income. As suggested in the fuel tax increase scenario forecast in the following chapter (Chapter 17), however, fuel price increases as results of fuel tax increases do not seem to cause significant reactions in vehicle market share, hence the insensitivity of average fuel intensity.

In addition, the projected average new LDV fuel intensities have been compared with NRCan's estimates (NRCan 1997), the EEA's estimates (EEA 1999b), and the historical data from the VFEIS database (TEUD 1996), as shown in Table 16-8. The fuel intensity values for 1990 and 1991 are historical data. All of them are the average fuel intensity measures of new LDV, except for VFEIS data which is the average fuel intensity of LDV stock. Obviously, the 1990/1991 average new LDV fuel intensities based on the VFEIS database would be lower than the stock average intensity, 8.55 ltr./100km. As such, the NRCan estimates and EEA estimates are both much higher than the VFEIS data and the data used in this study, which was derived from the Canadian Vehicle in Operation Census database (DesRosiers 1992). Correspondingly, this forecast suggests a lower average fuel intensity in 2010 than the NRCan's and EEA's estimates. As well, the rate of improvement is lower in this forecast than the NRCan's and EEA's estimates (EEA has calibrated its forecast to the NRCan's estimate).

Table 16-8: Average Canadian new LDV fuel intensity (Ltr./100km)

Source	1990	1991	2010	Improve
This forecast		8.20	7.68	0.52 (from 1991)
NRCan estimates (1997)	10.88		10.15	0.73 (from 1990)
EEA estimates	9.17		8.44	0.73 (from 1990)
VFEIS (LDV stock)	8.55	8.62		

For the historical data/estimates, the average fuel intensity value provided by this study is believed to be most credible, since it is based on the vehicle census database and the fuel efficiency rating by size class. For the 2010 forecast, it is found that the calibration of the DOE's fuel efficiency improvements by size class according to NRCan's aggregate estimates is questionable, since NRCan's estimates have taken sales mix shift into consideration. It is expected that, by averaging the DOE's projections of new LDV fuel efficiency by size class, according to the forecast of new LDV market share produced in this study, the forecast of average new LDV fuel intensity improvement from 1991 to 2010 would be larger than the current forecast produced through this study (c.f. Chart 2 in Section 16.1). This refinement, however, has not been conducted. Time is the main reason. Also, it is not the intent of this thesis to produce an official forecast.

16.5 Forecast Calibration

A way to improve the reliability of model-based forecast is calibration – to calibrate the forecast according to historical data. Calibration can also make forecasts at different levels of details consistent to some baseline forecast, such as the NRCan's Eenergy Outlook. As it is not the intent of this study to provide an official forecast, calibration has been performed only for the national level forecast of new LDV market share, according to the 1995 historical data of new car vs. light truck share presented in NRCan's Outlook (1997). There is an approximately 10% difference between the projected car-to-truck shift and the historical record. The passenger car share in 1995 as well as after 1995 was therefore reduced by a total of 10%, with each size class reduced according to its weight in the total car share. The same calibration was performed for light trucks by an addition of the 10% to its total share. Rather than distributing the share among the classes according to the class' share in the total share, however, the addition was made only to the size classes that are significantly rising in the forecasting period, namely small utility vehicles, small vans and small pickup trucks. Within these three classes, the 10% was distributed proportionately to each class according to each class' share in the total share.

Chart 18 shows the calibrated new LDV sales mix forecast in the coming decade. The adjustment resulted in a much more significant shift of new LDV sales mix than that before the calibration (Chart 1). According to this projection, small utility trucks would increase by 90% from 1991 to 2010, followed by small pickup trucks which would increase by 80%. Small vans would increase over 50% over the same period. The largest decrease would still take place in the market share of sub-compact cars (over 40%). All other size classes would basically remain the same in 2010 as in 1991, but compact cars and wagons show clear trends of increase in the coming decade.

Chart 18
Forecast of Class Shift of New Light Duty Vehicle Sales - Canada (Calibrated)

16. 6 The Validity of Spatial Econometric Models for Forecasting: A Brief Discussion

In terms of new LDV sales mix forecast, the primary consistency between the forecasts produced from the time-series based econometric models (such as J.D. Power's) and the spatial econometric models is comprehensible. Given that vehicle choice decisions are mainly related to demographic factors, vehicle characteristics, fuel price, and house income, a theory underlying vehicle sales mix forecasting is that vehicle market share (or equivalently, user's vehicle choice decisions) would correspond to any changes that may occur with these related variables. Be it the time-series based or spatial econometric models, the reliability of the forecast depends on two factors: the capability of these related variables in explaining user's vehicle choice decisions; and the stability of these relationships over time. As long as a similar set of variables is explored, and the models are well developed, the forecasts from these models should suggest similar trends.

However, this similarity is not readily comprehensible, since time-series data are often seen necessary in developing models for forecasting. Conceivably, a brief thought of using cross-sectional data for vehicle sales model building and forecasting could easily yield such a question: what if some phenomena, such as economy or fuel price, were abnormal in that modelling year? A detailed look at the spatial econometric models with respect to the two forecasting reliability issues can help understand the rationale of forecasting based on spatial econometric models.

First, the explanatory capabilities of models are often constrained by the availability of potential explanatory variables. Obviously, there are more opportunities to collect geospatial data than time-series data, since it is difficult to create a historical data set if the historical records are not available. As a result, spatial econometric models can often be developed based on a much larger sample, with a wider range of variables available for testing explanatory capability. This is exactly true for the new LDV sales mix modelling. The sample size for the spatially based vehicle sales mix models is 284, while time-series data are mostly limited in their sample size (a good expectation would be

above 30, but mostly less than that in reality). For explanatory variables, the population Census data allows for an extensive exploration of demographic factors in relation to user's vehicle choice decisions. Such variables are very limited in available time-series data.

There does, however, exist an explanatory method in time-series based modelling that the spatial econometric approach cannot use, namely the inclusion of time as an explanatory variable, to show a temporal trend of the forecasting variable that cannot be explained by any other variables. In the case of new LDV sales mix modelling, however, no such a variable has been found in the market share models that have been examined (such as the models in FEM by U.S. DOE). This suggests that vehicle choices are attributable, primarily if not completely, to social, economic and vehicle characteristics. On the other hand, the inclusion of such a variable in a time-series based vehicle share model may also be dangerous, since the temporal trend of a certain shift may not last over time.

Secondly, the factor of relationship stability (or structure stability) is a common challenge for forecasting, whatever the models are. The reason is that everything is changing in the universe; the causal relationships that the models represent are included. New vehicle models may appear in some vehicle classes that may draw great interest from the consumers, thus affecting the factors that the consumers normally consider in choosing a vehicle. The big shift from cars to light trucks in the early 1990's, as discussed in the last section, is an example. No models, be it time-series based or spatially based, can handle this kind of change. To deal with this challenge, it is usually advisable to use most up-to-date data for modelling, and to forecast (or extrapolate) only for a short to medium time horizon. The farther the forecast goes, the less reliability the result will have.

However, if a new vehicle model of this kind appears in the data-sampling period (e.g. sport utility vehicles and small vans in the current case), spatial econometric models could be more capable of capturing the trend. This is because, the spatial econometric approach implies that vehicle choice options are equal to all the observations (Census Divisions in the current case), and in turn to all consumers. Consumers' new preferences

as well as other constraints are thus taken into consideration in the modelling process. For the time-series based approach, however, this consideration may become very difficult, since not all the observations (yearly data), or in turn the consumers who purchase vehicles in different years, are faced with the same vehicle choice options. The explanatory variables would therefore have different relationships with the forecasting variables, namely vehicle market share, during different periods. This problem could be solved by splitting the time series data into different time regimes. But this would reduce the already small samples of time-series data, which are usually the case, into even smaller ones, affecting the reliability of model estimation.

As for the question of abnormal data in a modelling year, it is essentially not a serious concern. For such an abnormal year, consumers may find more or less constraints (e.g. financial constraints) on vehicle choice decisions. The choices would correspond to changes in the constraints for individuals. Consequently, the market share of new vehicle sales would reflect these changes. Statistically, however, there would be no fundamental changes in the relationships between the constraint variables and the vehicle choice decisions. As the financial constraint is loosed in the second year, for example, there may see higher market share of more expensive cars.

In sum, there is no fundamental difference in using the time-series based vs. spatially based models for forecasting new LDV sales mix. A key in developing spatial econometric models, in particular spatially-based new LDV sales mix models, is to ensure that new vehicle models be covered in the sample data.

Chapter 17

Policy Scenario Forecast: Gasoline tax Increases

As shown in the new LDV market share models (Models Classes 3 – 15), annual vehicle purchase and fuel cost of each vehicle class relative to the average cost (*i.e.* $anpfs_{ij}$) is a major predictor variable in virtually all the models. This relative cost, as defined in Equations 13-10 to 13-14 in Section 13.2.1, depends on vehicle class and fuel price. Thus, by adding an assumed magnitude of gasoline tax increase to the projected fuel price used in the business-as-usual forecast, while keeping other assumptions unchanged, a rerun of the same forecasting procedure resulted in a new LDV sales mix scenario based upon the assumption of a gasoline tax increase. By comparing each new LDV fuel intensity scenario, which was derived based on the sales mix scenario, with the business-as-usual scenario, the potential reduction effects of the gasoline tax increase options on average fuel intensity were derived.

The following two maps show the potential reductions of average new LDV fuel intensity as a result of gasoline tax increase by \$0.05 and \$0.50 per litre, respectively. Under the \$0.05 tax increase scenario, the potential reductions of average new light vehicle fuel intensity would range from 0.1% to 0.8%, with the mean being 0.33%. The potential reduction would increase with the increase in the magnitude of the gasoline tax. Under the scenario of a \$0.50 gasoline tax increase, the potential reductions would range from 1.5% to 3.3%, with the mean increasing to 2.32%. Obviously, a 2.32% reduction of average new light vehicle fuel intensity would be insignificant compared to the magnitude of a gasoline tax increase of \$0.50, which is unlikely in Canada in the foreseeable future.

The scenarios also exhibit significant spatial differences. In the \$0.05 increase scenario, the average fuel intensity in Quebec and the Atlantic provinces is more insensitive to gasoline tax increase than most other areas. Eastern Quebec and the lower mainland BC

are least sensitive to \$0.05 tax increase. In comparisons, the Prairie provinces and Northern Ontario would show the largest sensitivity.

Policy Scenario Forecast of New Light Duty Vehicle Fuel Intensity for 2010: Fuel Tax Increase by \$0.05

Fuel Intensity Reduction (%)

Policy Scenario Forecast of New Light Duty Vehicle Fuel Intensity for 2010: Fuel Tax Increase by \$0.50

Fuel Intensity Reduction (%)

Summary and Conclusions of Part III

Significant effort has been made to explore the feasibility of the spatial econometric approach to the development of policy decision support tools in general, and the modelling and forecast of new LDV class mix and average fuel intensity in particular. While there is still room for improvement, the following summary and conclusions can be drawn with regard to the models and their capabilities, the factors determining new LDV market share, the likely trends of new LDV sale mix and average fuel intensity, the regional differences in new LDV sales mix and average fuel intensity, and the main questions proposed for this research.

New LDV Sales Mix Models and Their Characteristics

Based on the 1992 Canadian Vehicle in Operation Census database (augmented with vehicle size and fuel efficiency ratings), the 1991 Census database, and numerous other vehicle related and geographical data sets, 14 spatial econometric (regression) models have been developed, with 13 dealing with new LDV sales mix by size class, and 1 with new LDV sales. With careful consideration given to the purposes of the models, the resulting new LDV market share models have the following major characteristics:

- (1) The models can be used to forecast Canada' new LDV sales mix shift attributable to changes in demography, economy, vehicle price, fuel price and the improvement of fuel efficiency technology;
- (2) Spatially, the models are disaggregated into Census Divisions. This level of disaggregation meets the current need for policy analysis to be performed at the levels of urban centres and small regions. Policy assessments at higher levels (such as the provincial and national levels) can be supported as well by aggregating the forecast by Census Division to the corresponding level.
- (3) Vehicles are disaggregated into 13 size classes (three wagon classes merged into one), allowing for more accurate estimation of average vehicle fuel intensity;

- (4) The models are sensitive to changes in policies with respect to vehicle and fuel pricing, and vehicle fuel efficiency improvements, allowing for integrated assessments of the relevant policy measures;
- (5) The forecast of new LDV market share based on these models can be used to derive the market share of passenger cars/cargo trucks, and of cars/trucks; the average fuel intensity can be calculated at these partitions as well, and used to roughly compare with the Canadian Average Fuel Consumption standard (CAFC);
- (6) The explicit specification of demographic factors in the models makes them potentially useful in the design of public awareness programs related to vehicle fuel efficiency, and in assessing policy impacts on population groups.

Major Determinants to New LDV Sales Mix

An extensive exploration of relationships between the vehicle market share and the demographic, economic, geographic and some vehicle-related variables has yielded the following insights with regard to new LDV sales mix:

- (1) New LDV market share can mostly be explained by the following variables: cost of purchasing and fueling a vehicle relative to the average cost, population age, household income, occupation, and such geographical factors as spatial dependence, population density, and local preference;
- (2) Of the non-geographical explanatory variables, the weights of contribution to the models generally follow such a sequence: relative vehicle cost, population age, household income, and occupation;
- (3) For each vehicle class, the lower the relative vehicle cost, the higher the market share;
- (4) Younger people purchase more subcompacts, compacts, vans and small utilities, and older people more midsize cars, large cars, two-seaters, wagons and small pickups;
- (5) High household incomes correspond to more two seaters, large cars, midsize cars, small utilities, and small vans, and low incomes to more subcompacts, compacts, and large pickups;

- (6) Some general relationships between vehicle class market share are evident: the more subcompacts and compacts, the less midsize cars, large cars, small vans and small utilities; the more midsize cars and large cars, the less small utilities; and the more passenger cars, the less cargo trucks;
- (7) The largest market share of large cars and large pickups are found in farming areas; the largest market share of small pickups are found in forestry areas;

Table III-1 summarizes the socio-economic and vehicle related variables included in the major market share models. The variables are ordered according to their weights of contribution to the corresponding model, with signs of the contribution associated with it (i.e. whether the contribution is positive or negative).

Forecast of New LDV Sales Mix Shift and Average LDV Fuel Intensity: the Business-as-usual and Fuel Tax Increase Scenarios

A forecast of new LDV sales mix and average LDV fuel intensity has been produced at the Census Division, provincial and national level, on the assumption of no policy intervention. Before calibration, this forecast reveals the following trends of new LDV sales mix shift as results of the coming changes in demographic, economic, and vehicle purchase and fueling cost:

- (1) Overall in Canada, the shifts of new LDV sales mix caused by changes in demographic, economic and vehicle related factors would be moderate from 1992 to 2010. The major shifts would take place from subcompacts (8.5%) into other passenger cars, especially into small utilities (3.3%), midsize cars (1.83%), and small vans (1.5%).
- (2) The market share of small utilities would see the largest rate of increase (49.6%), while those of subcompacts would have the largest rate of decrease (32.8%). There would be also significant increases in the shares of small pickups (41.1%), small vans (15.9%), midsize cars (12.0%), large cars (5.7%), and a decrease in those of large

pickups (13.4%). The increase in the market share of compact cars would be insignificant (2.4%).

Table III-1: Predictor variables in the new vehicle market share models

Major SIZE Class (take over 95% of new LDV shares)	Thematic variables (ordered according to their weights in explaining the corresponding market share)	Positive (+) / negative (-) contribution
Subcompacts	Population age group 25-44	+
	Relative vehicle purchase and fueling cost	+
	Household income	-
Compacts	Relative vehicle purchase and fueling cost	+
	Population age group 25-44	+
	Household income	-
Mid size cars	Population age group 55-75	+
	Relative vehicle purchase and fueling cost	+
	Household income	+
Large size cars	Population age group 55-75	+
	Relative vehicle purchase and fueling cost	+
	Household income	+
	Percentage of farming occupation	+
Small pick-ups	Relative vehicle purchase and fueling cost	+
	Population age group 55-75	+
	Percentage of forestry occupation	+
	Population density	-
Small vans	Relative vehicle purchase and fueling cost	+
	Population age group 30-44	+
	Household income	+
Small utilities	Population age group 25-44	+
	Household income	+
	Relative vehicle purchase and fueling cost	+
Standard pick-ups	Percentage of farming occupations	+
	Relative vehicle fueling cost	+
	Household income	-
	Percentage of forestry occupation	+

- (3) A significant drop in the passenger vehicle share is found during the period from 1991 to 1993 in the forecast. It is due to a sudden drop of the vehicle price advantage of subcompacts and compacts in that period. This shift is consistent to the historical new LDV vehicle sales data from 1991 to 1993, presented by the Transportation Energy Use Division at NRCan (TEUD 1996).
- (4) Overall, the aging of the population would cause increases in the market share of midsize and large cars, while a reduction of the younger population would lead to decreases in the market share of subcompacts, compacts, small vans, and small

utilities. This aging effect, however, would be, to some extent, reduced by the rising of the relative cost of midsize and large cars, and the lowering of the relative cost of compacts, small vans and small utilities. An exception occurs for subcompacts, for which the aging effect would be significant due to the fact that there would be no major increase in their price advantage. The largest increase in the market share of small utilities is mainly due to their large sensitivity to income increase, although the decrease in the relative vehicle cost also contributes to this.

- (5) Overall in Canada, the average new LDV fuel intensity would improve moderately (by 5.9%) from 1991 to 2010. The rate of improvement would be close to zero before 2000 and increase afterwards.

After being calibrated to the 1995 historical data of car-to-truck ratio, the forecast suggests a much more significant shift of new LDV sale mix from 1991 to 2010. Significant increases in the market share are expected for small utilities by 90%, small pickup trucks by 80% and small vans by over 50%. Subcompact cars are expected to decrease by over 40%, with the changes in other vehicle shares expected to be insignificant.

A policy scenario forecast of average new LDV fuel intensity has further been generated, on the assumption of a gasoline tax increase by \$0.05 and \$0.50 respectively. The results suggest that gasoline tax increase would not be an effective measure to improve average new LDV fuel efficiency.

Regional Differences in New LDV Sales Mix, Average Fuel Intensity, and Their Trends

Significant regional differences in new LDV sales mix, average fuel intensity and their trends are revealed in this study. They can be characterized as follows:

- (1) The distribution of new LDV classes follows the following spatial pattern across Canada: the largest market share of subcompacts and compacts are found in Quebec and the Atlantic provinces; the largest market share of midsize cars and the second largest market share of large cars are in Ontario; the largest market share of large cars and the second largest market share of pickup trucks are in Manitoba and Saskatchewan; the largest market share of pickups are in Alberta; and the largest shares of small utilities and two-seaters are in BC. In terms of average fuel intensity, generally, the further east, the lower fuel intensity. Alberta was the most fuel intensive, and Quebec the least fuel intensive.
- (2) Still at the provincial level, and on the assumption of business-as-usual, the largest rate of decrease in the subcompact market share would be found in Alberta (54.2%), and in large pickups, in Saskatchewan (31.8%). The fastest growth in vehicle market share would take place as follows: compacts by 33.0% in Saskatchewan, midsize cars by 27.6% and large cars 31.5% in Alberta, small vans by 33.5% in the Atlantic provinces, small utilities by 62.0% in Ontario, and small pickups by 39.0% in Alberta. In terms of average fuel intensity, Quebec would keep its leading position in average vehicle fuel intensity throughout the forecasting period. Ontario and the Atlantic provinces would be close to Canada's average. BC would be the highest in the West. The highest rate of improvement would be found in Saskatchewan (by 8.7%). Alberta would be the lowest both in average fuel intensity and in the rate of improvement (by 5.4%).
- (3) In the Windsor-Quebec Corridor, generally, the market share of subcompacts, compacts, midsize cars, large size cars and small vans were high in 1991, and those of small utilities and pickup trucks were low at the same time. Within this Corridor, the more south-west, the more midsize cars, large size cars, small vans and small utilities,

and the more north-east, the more subcompact and compact cars. Similar to the Corridor, the lower mainland BC area had a high market share of subcompact cars as well. Unlike the Corridor, however, this area had low market share of compact, mid size and large size cars, and high market share of small pickup trucks and small utility vehicles. As a result, the average fuel intensity was low in the Windsor Quebec Corridor, and low to average in the lower mainland BC, compared to other areas of Canada.

- (4) Assuming no additional policy intervention, the subcompact market share would decrease significantly in both the Corridor and the Lower mainland BC over the forecasting period. For the Corridor, the most significant increase would be seen in the sales of small utility vehicles, followed by small vans. In contrast, the most significant sales growth would be seen for midsize cars in the lower mainland BC. Despite such opposing changes, however, the Corridor and the Lower Mainland would remain high in midsize cars and small utility vehicles, respectively, as they were in 1991. In terms of average fuel intensity, the rate of improvement would be similar in the two areas, with relative average fuel intensity remaining the same as in 1991, namely low in the Corridor, and low to average in the Lower Mainland.
- (5) For the three major urban centres, Montreal had the largest market share of subcompacts and compacts in 1991 (about 10% more than in Toronto and Vancouver). Toronto had the largest shares of midsize and large cars. And Vancouver had the largest shares of small utility and pickup trucks. Small vans had similar share in Toronto and Vancouver, but less in Montreal. Wagon had similar shares in Montreal and Toronto, but less in Vancouver.
- (6) Without additional policy intervention, subcompacts would decrease in all the urban centres, with the rate of decrease less significant in Montreal and more in the other urban centres. The market share of compact cars would increase in all the centres, with Montreal remaining the largest. For midsize cars, large cars and wagons, the largest growth rates would be seen in Vancouver, but Toronto would continue to retain the largest shares. The pickup truck shares would continually be highest in Vancouver, with small pickups to increase and large pickups to decrease. Small vans would see similar rates of increase in all the centres. The growth in small utility share

would be more significant in Toronto and Montreal, but Vancouver would retain the largest share.

- (7) With a policy intervention of gasoline tax increase, Ontario shows the highest sensitivity to small tax increases, and the prairie provinces to large tax increases.

General Conclusions

With regard to the general research questions addressed in this research, the following conclusions have been reached:

- (1) The methodology and technology for spatial statistical modelling are solid and effective in producing spatial econometric models that are reliable according to probability theory. The lack of certain models in the statistical software can be dealt with by using appropriate modelling methodologies. The modelling environment, including GIS, statistical software, multi-dimensional data visualization software, and the linkages between them, has proven to be capable of supporting the modelling process. By constructing appropriate indicators from independent variables, policy variables can be included in the models, to allow for relevant policy assessments.
- (2) Existing spatial information is adequate for estimating new LDV market share. Market share models for all the major vehicle classes have been estimated with model quality parameters exceeding 85%. Most variables that are expected to contribute to vehicle choice decisions have been tested during the modelling process, and included in the models where appropriate. The Canadian Census database served as a rich source for this purpose. Furthermore, projected data for these explanatory variables are also found available for the needs of forecasting.
- (3) Spatial econometric models can be used for short to medium term forecasting, on the assumption that there would be no significant changes in the relationships between the forecasting variable and the explanatory variables, over the forecasting period. In essence, as long as the change in the forecasting variable can be explained by the changes in the explanatory variables, there is no fundamental difference in using

spatial econometric models vs. time-series based econometric models for forecasting. This is the case for the new LDV sales forecasting.

Thus, geomatics science and technology, in particular spatial statistics in combination with GIS, provides an alternative approach to the development of policy supportive models that deal with sustainable development issues in general, and climate change or transportation fuel efficiency issues in particular. This alternative creates significant new possibilities:

- (1) It allows for the integration and use of a wealth of geospatial information, including social, economic and environmental, for model building. Such information has been increasingly made available through different means, including Census, statistics survey, GIS, and remote sensing. As such, it offers an alternative for model development when the standard econometric or discrete choice modelling approaches are not applicable due to data limitation.**
- (2) Its ability of integrating and using geospatial information for model building also enables the consideration of a much larger array of explanatory variables for model building. As such, it offers an opportunity to produce more reliable policy supportive models, even when data are available for standard econometric modelling or discrete choice modelling. More importantly, it provides a means for the integration of social, economic and environmental factors in policy scenario assessments, thereby facilitating the process of sustainable development policy-making.**
- (3) Its ability to model at the local level and generalize to more aggregate levels, along with its associated visualization technology, makes it a powerful tool for revealing regional differences in historical data, the forecast, and the likely magnitude of change. Further analyses of these data, in combination with other related variables, could yield a wide range of insights for the assessment of potential policy impacts.**

Chapter 18

Summary, Conclusions and Future Research

Sustainable development represents a significant opportunity to help humanity to reconcile the apparent contradiction between development and the environment. Given the fact that the causes of the environmental crisis are deeply rooted in modernism, the success of the reconciliation entails a fundamental transformation of the modernist concept and practice. The key to this transformation is a coherent integration of the quintessence of Western and Eastern civilizations, namely the reductionist and the holistic approaches. In particular, scientific, reductionist materialism should be shifted to the rising, holistic worldview, which recognizes the planet as a unified, dynamic and organic system in which humanity is only a part. Individualism that is underpinned by reductionism should be substituted by the ethic of individual-in-community, which acknowledges the rights and benefits of individuals, and at the same time emphasizes the constraints of the community context on individual rights and benefits. Consistent with this ideology, the market-oriented economy should in addition be equipped with features that ensure the control of resource throughputs and income redistribution, in order to ensure intergenerational and intragenerational equity and the welfare of nature, and that takes a precautionary approach to the earth's life support system, with the recognition of the limitations of human understanding of nature.

Consistent with, and in support of, this transformation process, the modern, reductionist scientific paradigm must integrate a holistic approach into its practice. The holistic approach appreciates a systems perspective, and emphasizes interdisciplinary and transdisciplinary inquiries for the interfaces and interactions between disciplines, and for the complex interrelationships between the various components of the earth system. Furthermore, for any movement towards this transformation, participatory democracy is critical, voices from different regions and different groups must be heard, and public education is fundamental.

As an initial step towards sustainable development, the mainstream approach, as represented by Agenda 21, aims to take environmental sustainability into consideration while reviving economic growth. Its core apparatus is public policy, supported by scientific information.

The environment is spatial. Geomatics as a technological science that deals specifically with spatial information could therefore make major contributions to the policy-making process. Currently, however, its contributions are limited. Gaps exist with respect to both data and technology. Availability and consistency comprise the major issues with regard to data. Data models, modelling capability, analytical capability, and user-friendliness are the major impediments in terms of technology.

To substantially advance the role of geomatics in support of sustainable development policymaking, this thesis has proposed an integrated solution, namely the development of an on-line national policy atlas for sustainable development. Such an atlas would bring to policy makers comprehensive, integrated geospatial information structured according to policy issues. Within such an informational environment, the atlas would further allow the policy analysts to perform spatially-based policy analysis and scenario assessments. Moreover, it would provide policy decision makers and other policy participants with a "live" policy document, which allows for the retrieval of policy supportive knowledge, the browsing of the related geospatial information, and the further exploration of policy scenarios when needed.

For the implementation of such an atlas, one major research topic must be addressed, namely the feasibility of developing spatially-based models for the atlas in support of policy scenario assessment. Based on the case of supporting greenhouse gas reduction policy-making, this thesis has addressed this topic, using a spatial statistics approach. The study has produced a range of particular outcomes, which were summarized in the conclusions of Part III. The study has concluded that spatial statistics modelling is feasible for the development of predictive models in support of vehicle fuel efficiency policy design in particular, and sustainable development policy-making in general. At

the same time, it has revealed that this approach has numerous advantages that complement the approaches currently used in the policy domain. First, its dependence on geospatial data for modelling offers an opportunity for model development in which data required for other approaches are inadequate. Second, it allows for the integration of a variety of variables available in different spatial frameworks, therefore offering an opportunity for the development of more reliable predictive models, and more importantly, for the consideration of social, economic, and environmental factors in policy decisions. Finally, it provides a powerful tool for revealing regional differences. As such, it could potentially improve sustainable development policy-making.

Many other research topics remain to be addressed in order to implement the atlas. Among others, spatial analysis functions that are pertinent for discovering policy supportive knowledge need to be identified and/or developed. The search for problem areas, the identification of factors related to the problem, and the assessment of potential impacts of policy options are some examples. The need for making the analytical functions user-friendly, and for access to the knowledge discovered through the analytical processes, has further raised a number of research issues dealing with the adaptation of business intelligence technologies to the spatial, policy context. More specifically, On-Line Analytical Processing (OLAP) technology, which is characterized by a multi-dimensional database that enables the user to look at data from different perspectives (i.e. dimensions), may be adapted to the atlas context, to allow for spatial analysis across multiple maps and multiple spatial frameworks. Data mining technology, which aims to extract rules and patterns hidden in data, has the potential to improve the user-friendliness of analytical functions for policy analysis. At the same time, the technology may enrich the means for knowledge discovery in the atlas context. Moreover, policy supportive knowledge needs to be stored and made accessible to policy decision makers. Knowledge access technology, a more recent advancement in the business intelligence domain, may be borrowed to fulfil this need, although considerable research effort would still be required for the adaptation. The adaptive research topics include the design of an appropriate knowledge base for spatially-based policy supportive knowledge, the

development of a knowledge query builder, and the development of an explanatory mechanism to respond to the user's query on the process of knowledge derivation.

With regard to the content of the atlas, research efforts are required for the construction of map content to address defined policy issues, and for policy analysis and scenario assessments in order to generate policy supportive knowledge. Spatially-disaggregated models, if unavailable, may also need to be developed in order to support policy scenario assessment. The efforts could start with the policy issue of climate change. A structure of map content should be developed to address this priority policy issue, based on the policy issue map model of the atlas (Figure 9-2). Knowledge required for supporting climate change policymaking should be identified or conceptualized, with an initial focus on greenhouse gas reduction policies. With regard to predictive models for policy scenario assessment, an immediate effort should be made to incorporate more recent data and more variables, if available, to further refine the new light duty vehicle sales mix and, especially, sales models developed through this thesis research. An effort may further be made to develop spatio-temporal models using the relevant geospatial data sets collected for several years, as recently suggested by the policy developers. Expansions should further be made to address alternative vehicles, alternative fuels, distance travelled, and medium and heavy-duty vehicles. By using a phase approach, the modelling scope could be expanded gradually to the whole transportation sector, and moreover, to other energy sectors. The goal is to develop spatially-disaggregated predictive models that are capable of forecasting total greenhouse gas emissions and the related policy scenarios at the local level, which is of critical importance for policy-making aimed at greenhouse gas reductions.

In sum, this thesis research has made significant contributions to the advancement of the application of geomatics to sustainable development policy-making. The following contributions are of particular significance and originality:

- (1) The proposed conceptual model of an on-line national policy atlas for sustainable development represents a major advancement in seeking geomatics solutions to supporting sustainable development policy-making. At the same time, the model can

serve as a research agenda for the implementation of the concept, following which fruitful research outcomes are foreseeable.

- (2) The case study has demonstrated the feasibility of spatial statistics in combination with GIS for developing predictive models in support of policy scenario assessments. It has also showcased an application of geomatics to addressing such policy issues to which the solutions are spatially important but implicit. Furthermore, the case study has revealed the unique merits of the spatial statistics approach to model development in support of sustainable development policy-making.
- (3) The new light vehicle sales mix models developed through this case study have several characteristics that are original and useful in support of policy-making aimed at fuel efficiency improvements. First and most distinctively, it allows policy assessments to be performed at the local level, which is critical for current fuel efficiency policy-making. Second, it has incorporated fuel efficiency technology improvements by vehicle size class into the models, therefore enabling the assessment of the impacts of policy measures aimed at accelerating the market penetration of fuel efficiency technologies on new light duty vehicle sales mix. Third, in addition to its sensitivity to fuel price, it is also sensitive to vehicle purchase price, therefore allowing for testing such fiscal measures as vehicle feebate schemes²⁸ that are aimed at gearing consumers' vehicle choice decisions towards more fuel efficient vehicles. Fourth, an extensive exploration of the relationships of demographic factors with new light duty vehicle market share was performed during the process of model development. As a result, the models are able to track the impacts of demographic trends on new light duty vehicle sales mix. This ability is of considerable importance for policy scenario assessments, since an aging population will be the most distinctive demographic characteristic of Canada in the coming decades. In addition, a variety of geographical variables have been tested during the modelling process, including road density, urban/rural driving and population density. All these analyses are valuable for policy design as well as for other similar research endeavours.

²⁸ A vehicle feebate policy levies surtaxes (i.e. fees) on high emission vehicles and tax rebates on low emission vehicles, based on the rationale that the social cost of pollution as an externality of vehicle use should be internalized by making the polluter pay for the pollution.

- (4) The study has further produced a business-as-usual forecast of new light duty vehicle sales mix and average fuel intensity at the local level (Census Division), which has allowed the generation of a wide range of insights with respect to their spatial patterns, their likely changes in the near future, and the spatial patterns of the changes. These insights are of considerable value for policy development. At the same time, they have clearly demonstrated the importance of considering spatial diversity in fuel efficiency policy design in particular, and in sustainable development policy-making in general.

In addition, this research has also made the following contributions:

- (1) The discussion of the theories and methodologies for sustainable development is a contribution to the discourse of sustainable development. A distinctive point in this contribution is the integration of the author's personal experience with both the Eastern and Western societies into the analysis of sustainable development approaches. This discussion also provides a concise summary of the theories and methodologies for sustainable development for researchers and practitioners whose work is related to sustainable development.
- (2) The characterization of the processes of climate change policy-making is useful for GIS practitioners who are seeking geomatics-policy marriages as well.
- (3) The depth-hermeneutical approach to the analysis of geomatics potential to supporting sustainable development policy-making has led to the identification of the gaps between geomatics and sustainable development policy-making, which are useful for further research initiatives aimed at closing these gaps.
- (4) The forecast of the fuel tax increase scenarios provides a reference for vehicle fuel efficiency policy design. It also showcases the capability of spatially-disaggregated models in support of policy scenario assessments.

Some major research challenges still remain but this thesis has demonstrated in concrete terms the potential of modern geomatics for effective policy-making for sustainable development.

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Appendix 1

Data Source Descriptions

A.1 Data for Modelling

1992 Canadian Vehicle in Operation Census database. This database, available at the Energy Sector, was produced by the company DesRosiers Automotive Consultants based in Toronto. It includes all light duty vehicles registered in Canada in 1992, each vehicle linked to the postal code in which it is registered. The database contains over 13,000 distinct vehicle configurations, characterized by model year, manufacturer, model name, body style, engine size, fuel system, and other technical attributes. It was augmented by NRCan's Transportation Energy Use Division with fuel consumption ratings and vehicle size class information.

1991 Census database of Canada. A National Census is conducted every five years by Statistics Canada. The 1991 Census database consists of two parts. Part A, which was produced based on every individual's response, contains 160 variables describing Canada's basic demographic characteristics, including population, population age group, ethnicity group, household and family. Estimated using surveyed samples, Part B includes over 500 hundred demographic variables, involving a wide range of demographic features such as language, religion, immigration, education, employment, occupation, and income.

1991 fuel price data. The historical data of fuel price was obtained from the Electronic Data Retrieval Service at Energy Sector. Two data sets were used to derive the required fuel price data: Pump Price Components for provinces and urban centres, and Petroleum Product Pricing Report for provinces and all provincial capitals.

1991 new light duty vehicle price data. The vehicle price data was obtained from the U.S. Department of Energy. The price is disaggregated into domestic and import groups, and available by 12 vehicle size classes which are consistent with the 15 size classes. A new vehicle sales data set came along with the price data. It was used as weights in aggregating the domestic and import prices into a weighted average.

1991-1993 new light duty vehicle fuel efficiency data. NRCan's Transportation Energy Use Division provided the fuel efficiency data by 15 size classes for the years from 1991 to 1993. The data was based on the Vehicle Fuel Economy Information System (VFEIS) - a database obtained from Transport Canada that contains new vehicle sales and a range of vehicle property descriptions including fuel consumption rate by city/highway. Vehicle size classes were associated with this database by Transportation Energy Use Division. Average fuel efficiency for each size class was derived by using new vehicle sales of different vehicle models as weights, and by combining city and highway fuel consumption rates weighted by 0.55 and 0.45 respectively.

Urban transit service data. This data set, covering the years from 1991 to 1994, was extracted from the Urban Transit Service database, which is developed and maintained by Canadian Urban Transit Association. A wide range of variables (approximately 250) are included in the data set, describing the areas of service, hours of service, fare structures, number of vehicles, energy consumption, service employment passengers, operation expenses and revenues.

Road transportation network data. The road network data was obtained from the GeoAccess Division. The data sets are separate by province, with five levels of standard roads represented. They are the data used for producing the 1992 provincial transportation network maps (1:2M) by Energy, Mines and Resources Canada.

1992 Family Expenditure Data. This data was acquired from Statistics Canada, in an attempt to construct the spatial variables of new vehicle purchase price, vehicle operating costs such as fuels, maintenance, insurance and registration.

A.2 Data for Projection

Projected demographic data. The demographic variables included in the models are: numbers of household, population, population age group, household income, and occupation structure. The projections of the former four variables for 1992 to 2010 were produced by CompuSearch (a company specializing in spatial data analysis and marketing research), at the Census Division level. The Energy Sector provided the provincial level projections for total number of household and population, which were used in producing the NRCan's Energy Outlook. Occupation structure projections for the years of 1991, 1996, 2000 and 2005 were obtained from Human Resources Development Canada.

Projected macro economic data. Variables dealing with macro economic situations include national personal income and fuel price. Projections of the former for 1992 to 2010 at the provincial level was produced by Informetrica and obtained from the Energy Sector. Fuel price projections from 1992 to 2010 were produced by Energy Sector in early 1996.

Projected vehicle related data. Fuel efficiency forecasts came from two sources: the Energy Sector for the aggregate estimates of vehicle fuel intensity improvements, and the Department of Energy (DOE) of US for the projection of fuel efficiency technology improvements disaggregated into 12 vehicle size classes. The latter was produced based on the Fuel Efficiency Model (FEM) used in producing 1997 US' Energy Outlook. Vehicle price forecast was obtained from DOE.

Appendix 2

Light Duty Vehicle Size Classification (ornl 1989)

Automobile Classes:

Two seater (class 1): cars designed to primarily seat two adults.

Minicompact (class 2): less than 85 cubic feet of passenger and luggage volume.

Subcompact (class 3): between 85 and 99 cubic feet of passenger and luggage volume.

Compact (class 4): between 100 and 109 cubic feet of passenger and luggage volume.

Midsize (class 5): between 110 and 119 cubic feet of passenger and luggage volume.

Large (class 6): 120 or more cubic feet of passenger and luggage volume.

Light truck Classes:

Small pickup (class 10): 2WD and 4WD trucks having Gross Vehicle Weight Ratings (GVWR) under 4,500 lbs.

Small van (class 11): As of model year 1989, all imported cargo and passenger vans and the following domestic ones:

- Chevrolet Astro
- Chevrolet Lumina APV
- Dodge Mini Ram Van
- Ford Aerostar
- GNC Safari
- Plymouth Town & Country
- Plymouth Voyager

Small utility vehicle (class 12): all other light-duty vehicles not in a car or truck class are classified as utility vehicles. As of model year 1989, all import utility vehicles with the exceptions as noted in "Large utility vehicle" and the following domestic ones are small utility vehicles:

- Chevrolet Blazer "S"
- Ford Bronco II
- GMC Jimmy "S"
- Jeep Cherokee XJ
- Jeep Wagoneer XJ
- Jeep Wrangler

Large pickup (class 13): 2WD and 4WD trucks having GVWR of 4,500 to 8,500 pounds.

Large van (class 14): as of model year 1989, all domestic cargo and passenger vans, with the exceptions as noted in "Small van".

Large utility vehicle (class 15): all domestic utility vehicles, with the exceptions as noted in "Small utility vehicle" and the following import utility vehicles:

- Range Rover
- Toyota Land Cruiser

- Note 1:** Curb weight - weight of a vehicle including all standard equipment, spare tire and wheel, all fluids and lubricants to capacity, full tank of gasoline, and the weight of major optional accessories normally found on the vehicle. Curb weight is 300 pounds less than inertia weight.
- Note 2:** Size classifications for automobiles are derived by the interior size of each vehicle, while size classifications for light-duty trucks are grouped by capacity in terms of gross vehicle (GVW) which is truck weight plus carrying capacity. Note that the light truck size classification scheme is not the one cited in Gas Mileage Guide, EPA, but the one defined in a SAE paper series by EPA staff [1] - [6].

Appendix 3

Estimates of New LDV Sales Mix and Sales Models

- **Estimates of New LDV Sales Mix Models**
- **Functions of Previous Year's New LDV Sales Mix**
- **Estimates of New LDV Sales Model**

Feb 7 1997 11:25:26 station Page 3

147	WSPR7099	0.201374	0.035482	3.430992	0.000204	"M
148	D19_ML1	1.716163	0.180164	0.947738	0.000000	"M
149	D19_ML3	-2.221119	0.294387	-7.436771	0.000000	"M
150						
151	Small pickups:					
152	*****					
153						
154						
155	METROGEOGRAPHIC ERROR MODEL (GROUPWISE)"					
156	ITERATED FULL ESTIMATION"					
157	DATA SET PHASES10"					
158	DEPENDENT VARIABLE	PRDALL	CRS 264			
159	R2	0.8940	Rm Corr.	0.9408		
160	LIR	-336.133	AIC	674.263		
161	Convergence after 8 iterations"					
162	VARIABLE	S.D.	S-value			
163	CONSTANT	2.76042	-3.848191			
164	PRDALL	0.674072	0.650626			
165	OC_F102	0.118625	2.811792			
166	A_F09_F2	0.118625	2.811792			
167	A_F09_F2	0.09033348	0.90917081			
168	PRD7_F0	0.06432463	0.90917081			
169	PRD7_F0	0.06432463	0.90917081			
170	PRD7_F0	0.14789	0.8167419			
171	PRD7_F0	0.14789	0.8167419			
172	D12_M1	-0.466331	0.131179			
173	D12_M1	2.51195	0.391992			
174	D12_M1	-2.477950	0.346302			
175						
176	Small vms:					
177	*****					
178						
179						
180	METROGEOGRAPHIC ERROR MODEL (GROUPWISE)"					
181	ITERATED FULL ESTIMATION"					
182	DATA SET PHASES10"					
183	DEPENDENT VARIABLE	PRDALL	CRS 264			
184	R2	0.8921	Rm Corr.	0.9506		
185	LIR	-336.390	AIC	724.779		
186	Convergence after 6 iterations"					
187	VARIABLE	S.D.	S-value			
188	CONSTANT	0.715947	0.71387			
189	PRD111	2.454038-05	5.972238-05			
190	A_F09_F2	0.00235518	0.00465674			
191	V778_F0	0.00235518	0.00465674			
192	PRD111	0.00235518	0.00465674			
193	V778_F0	0.00235518	0.00465674			
194	V778_F0	0.00235518	0.00465674			
195	D11_M1	0.471399	0.0603171			
196	D11_M1	2.51955	0.43429			
197	D11_M1	-2.93347	0.339036			
198						
199	Small utilities:					
200	*****					
201						
202	METROGEOGRAPHIC ERROR MODEL (GROUPWISE)"					
203	ITERATED FULL ESTIMATION"					
204	DATA SET PHASES10"					
205	DEPENDENT VARIABLE	PRDALL	CRS 264			
206	R2	0.9997	Rm Corr.	0.9323		
207	LIR	-443.194	AIC	996.300		
208	Convergence after 8 iterations"					
209	VARIABLE	S.D.	S-value			
210	CONSTANT	1.04043	0.643799			
211	PRD111	0.004313	0.004313			
212	A_F09_F2	0.004313	0.004313			
213	A_F09_F2	0.004313	0.004313			
214	D12_M1	11.4621	0.877093			
215	D12_M1	4.4727	0.357231			
216						
217	Large pickups:					
218	*****					
219						

[illegible]

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Page 4

220

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

221

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

222

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

223

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

224

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

225

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

226

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

227

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

228

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

229

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

230

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

231

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

232

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

233

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

234

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

235

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

236

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

237

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

238

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

239

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

240

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

241

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

242

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

243

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

244

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

245

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

246

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

247

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

248

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

249

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

250

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

PREDICTION

R2

R2 (Ruse)

SC

Small pickups:

251

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*M

ITERATED PLS ESTIMATION*H

DATA SET PHASE34 *H

DEPENDENT VARIABLE

 * FUNCTIONS OF PREVIOUS YEAR NEW LOW SALES MARKET SHARES *

Feb 7 1997 11:25:26

stdlin

Page 3

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147 HETPDA789 0.201574 0.055482 3.438992 0.000284*H
148 D79_ML1 1.719153 0.188104 9.740738 0.000000*H
149 D79_ML2 -1.321119 0.296287 -7.496771 0.000000*H
150
151 Small pickups:
152 *****
153
154 HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*H
155 ITERATED PLS ESTIMATION*H
156 DATA SET PHASE35 *H
157 DEPENDENT VARIABLE PREDIOL
158 R2 0.9540
159 R2 (Ruse) 0.9400
160 LK -326.133 AIC 674.265
161
162 Convergence after 8 iterations*H
163 B D. 0.000000
164 COEFFS 0.000000
165 PREDIOL 0.740738
166 TPR31 0.0740738
167 OC_PU_37 0.1184021 0.0267158 4.433176 0.000000*H
168 A_PU_37 0.000232488 0.000110041 -2.726380 0.000000*H
169 P757_PO 0.00432463 0.000770139 4.631964 0.000000*H
170 P757_APO 0.00370182 0.000466665 3.820091 0.000000*H
171 W757_PO 0.167789 0.01677419 3.820091 0.000000*H
172 D72_ML1 -0.646321 0.113175 -3.761796 0.000000*H
173 D10_ML2 2.31135 0.391992 6.407161 0.000000*H
174 D10_ML3 -2.477958 0.360362 -7.166164 0.000000*H
175
176 Small vases:
177 *****
178
179 HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*H
180 ITERATED PLS ESTIMATION*H
181 DATA SET PHASE36 *H
182 DEPENDENT VARIABLE PREDIOL
183 R2 0.8921
184 LK -354.396 AIC 726.179
185
186 Convergence after 6 iterations*H
187 B D. 0.000000
188 COEFFS 0.000000
189 PREDIOL 0.719047 0.071987 19.815905 0.000000*H
190 A_PU361 2.454828-05 5.972232-06 4.118423 0.000000*H
191 V_PU361 0.0029358 0.000462674 4.632335 0.000000*H
192 KLAB_MBC -5.5545-07 6.870148-07 -9.647285 0.000000*H
193 V_LAB-1.373942-06 1.430998-07 -7.810978 0.000000*H
194 W_L1_M 0.471399 0.0063571 5.358716 0.000000*H
195 D11_ML1 2.39395 0.62829 6.945439 0.000000*H
196 D11_ML2 -3.75367 0.350038 -8.618189 0.000000*H
197
198 Small utilities:
199 *****
200
201 HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*H
202 ITERATED PLS ESTIMATION*H
203 DATA SET PHASE38 *H
204 DEPENDENT VARIABLE PREDIOL
205 R2 0.9967
206 LK -443.194 AIC 696.366
207
208 Convergence after 8 iterations*H
209 B D. 0.000000
210 COEFFS 0.000000
211 PREDIOL 1.34043 0.043779 26.39737 0.000000*H
212 PREDIOL -0.094513 0.00786094 -13.325001 0.000000*H
213 A_PU381 7.064432-09 4.436488-06 15.325001 0.000000*H
214 D12_M11 11.6431 0.073093 13.377181 0.000000*H
215 D12_M12 4.4727 0.357531 13.399938 0.000000*H
216
217 Large pickups:
218 *****
219
220 HETEROSKEDASTIC ERROR MODEL (GROUPWISE)*H
221 ITERATED PLS ESTIMATION*H
222 DATA SET PHASE39 *H
223 DEPENDENT VARIABLE PREDIOL
224 R2 0.9713
225 LK -514.431 AIC 753.971
226
227 Convergence after 5 iterations*H
228 B D. 0.000000
229 COEFFS 0.000000
230 PREDIOL 0.9713 0.0713 31.431 0.000000*H
231 A_PU391 7.064432-09 4.436488-06 15.325001 0.000000*H
232 D13_M11 11.6431 0.073093 13.377181 0.000000*H
233 D13_M12 4.4727 0.357531 13.399938 0.000000*H

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Small pickups:

Feb 7 1997 11:25:26

stdin

Page 5

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293 Two-Samplers:
294 .....
295
296 SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION
297 DATA SET PHASE33 "M"
298 DEPENDENT VARIABLE PPOB3
299 SPATIAL WEIGHTS MATRIX CHOSSES "M"
300 L1K 25.4165 AIC -37.2329 SC -11.6901 "M"
301 L1K 25.4165 AIC -37.2329 SC -11.6901 "M"
302 SIG-SQ 0.0460864 ( 0.216533 ) "M"
303 VARIABLE COEFF S.D. Prob="M"
304 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
305 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
306 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
307 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
308 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
309 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
310 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
311 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
312 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
313 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
314 Minicompet:
315 .....
316
317 SPATIAL LAG MODEL - MAXIMUM LIKELIHOOD ESTIMATION
318 DATA SET PHASE33 "M"
319 DEPENDENT VARIABLE PPOB3
320 SPATIAL WEIGHTS MATRIX CHOSSES "M"
321 L1K 25.4165 AIC -37.2329 SC -11.6901 "M"
322 SIG-SQ 0.0460864 ( 0.216533 ) "M"
323 VARIABLE COEFF S.D. Prob="M"
324 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
325 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
326 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
327 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
328 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
329 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
330 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
331 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
332 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
333 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
334 Subsequent:
335 .....
336
337 HETEROGENEOUS ERROR MODEL (GROUPWISE) "M"
338 DATA SET PHASE33 "M"
339 DEPENDENT VARIABLE PPOB3
340 SIG-SQ 0.0460864 ( 0.216533 ) "M"
341 VARIABLE COEFF S.D. Prob="M"
342 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
343 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
344 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
345 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
346 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
347 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
348 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
349 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
350 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
351 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
352 Convergence after 9 iterations
353 VARIABLE COEFF S.D. Prob="M"
354 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
355 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
356 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
357 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
358 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
359 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
360 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
361 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
362 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
363 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
364 Subsequent:
365 .....

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Feb 7 1997 11:25:26

stdin

Page 6

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366 A_JIM91-4.13198-05 1.061945-03 -2.309082 0.000000 "M"
367 W_PPOB1 0.013643 0.483762 2.819790 0.000000 "M"
368 W_PPOB2 0.010138 0.461319 2.187289 0.000000 "M"
369 W_PPOB3 0.00277341 0.346532-05 6.435759 0.000000 "M"
370 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
371 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
372 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
373 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
374 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
375 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
376 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
377 Ordinary Least Squares Estimation
378 DATA SET PHASE33 "M"
379 DEPENDENT VARIABLE PPOB3
380 SIG-SQ 0.0460864 ( 0.216533 ) "M"
381 VARIABLE COEFF S.D. Prob="M"
382 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
383 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
384 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
385 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
386 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
387 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
388 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
389 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
390 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
391 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
392 HETEROGENEOUS ERROR MODEL (GROUPWISE) "M"
393 DATA SET PHASE33 "M"
394 DEPENDENT VARIABLE PPOB3
395 SIG-SQ 0.0460864 ( 0.216533 ) "M"
396 VARIABLE COEFF S.D. Prob="M"
397 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
398 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
399 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
400 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
401 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
402 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
403 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
404 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
405 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
406 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
407 Subsequent:
408 .....
409
410 HETEROGENEOUS ERROR MODEL (GROUPWISE) "M"
411 DATA SET PHASE33 "M"
412 DEPENDENT VARIABLE PPOB3
413 SIG-SQ 0.0460864 ( 0.216533 ) "M"
414 VARIABLE COEFF S.D. Prob="M"
415 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
416 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
417 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
418 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
419 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
420 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
421 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
422 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
423 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
424 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
425 Convergence after 7 iterations
426 VARIABLE COEFF S.D. Prob="M"
427 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
428 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
429 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
430 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
431 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
432 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
433 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
434 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
435 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
436 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
437 Subsequent:
438 .....
439
440 HETEROGENEOUS ERROR MODEL (GROUPWISE) "M"
441 DATA SET PHASE33 "M"
442 DEPENDENT VARIABLE PPOB3
443 SIG-SQ 0.0460864 ( 0.216533 ) "M"
444 VARIABLE COEFF S.D. Prob="M"
445 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
446 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
447 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
448 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
449 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
450 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
451 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
452 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
453 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
454 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
455 Convergence after 7 iterations
456 VARIABLE COEFF S.D. Prob="M"
457 W_PPOB1 0.003393 0.537922 7.362856 0.000000 "M"
458 W_PPOB2 0.013643 0.483762 2.819790 0.000000 "M"
459 W_PPOB3 0.010138 0.461319 2.187289 0.000000 "M"
460 W_PPOB4 0.00277341 0.346532-05 6.435759 0.000000 "M"
461 W_PPOB5 0.00277341 0.346532-05 6.435759 0.000000 "M"
462 W_PPOB6 0.00277341 0.346532-05 6.435759 0.000000 "M"
463 W_PPOB7 0.00277341 0.346532-05 6.435759 0.000000 "M"
464 W_PPOB8 0.00277341 0.346532-05 6.435759 0.000000 "M"
465 W_PPOB9 0.00277341 0.346532-05 6.435759 0.000000 "M"
466 W_PPOB10 0.00277341 0.346532-05 6.435759 0.000000 "M"
467 Subsequent:
468 .....

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Feb 7 1997 11:25:28									
stdlin									
Page 8									
512	ITERATED PLS ESTIMATION								
513	DATA SET	PROB14							
514	DEPENDENT VARIABLE	PROB14							
515	CONSTANT	0.6448							
516	SE	0.2114							
517	ADJ R-SQ	0.6448							
518	CONV	149.263							
519	ITERATIONS	7							
520	CONV	0.000000							
521	CONV	0.000000							
522	CONV	0.000000							
523	CONV	0.000000							
524	CONV	0.000000							
525	CONV	0.000000							
526	CONV	0.000000							
527	CONV	0.000000							
528	CONV	0.000000							
529	CONV	0.000000							
530	CONV	0.000000							
531	CONV	0.000000							
532	CONV	0.000000							
533	CONV	0.000000							
534	CONV	0.000000							
535	CONV	0.000000							
536	CONV	0.000000							
537	CONV	0.000000							
538	CONV	0.000000							
539	CONV	0.000000							
540	CONV	0.000000							
541	CONV	0.000000							
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Page 7									
439	ITERATED PLS ESTIMATION								
440	DATA SET	PROB14							
441	DEPENDENT VARIABLE	PROB14							
442	CONSTANT	0.6448							
443	SE	0.2114							
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Feb 7 1997 11:25:26 stdin Page 9

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585 RES      0.43444      P=0.002      Prob 1.2995e-14 "H"
586 TIC=00      0.0163822 ( 0.127997 ) 200-60(ML) 0.0163822 ( 0.127771 ) "H"
587 "H"
588 VARIABLE CORR      S.D.      t-value      Prob="H"
589 WM_ML_O      0.88046      0.0493648      12.711494      0.000000
590 "H"

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