Three Essays in Macroeconomics with a Focus on Economic Growth, Monetary Policy and Knowledge Dissemination

by

Samira Hasanzadeh

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial

fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Economics

Carleton University

Ottawa, Ontario

Abstract

This thesis includes three essays on empirical macroeconomics. The first chapter applies modern ideas-oriented growth accounting, based on the semi-endogenous growth theory of Jones (2002), to compare the sources of Canadian and U.S. economic growth between 1981–2014. Two features stand out in comparison to the U.S. growth experience over the same period. First, over a full percentage point of the average U.S. growth of 1.64 percent is due to excess ideas growth. Second, the constant growth view' that reconciles large sources of transitional growth with relatively stable average growth is not supported in Canada.

The second chapter of this thesis examines the empirical link between movements in interest rates and capacity utilization, using 2SLS fixed effects estimations in a panel setting of 21 U.S. manufacturing industries between 1975–2011. The study arrives at three main findings: (a) In most industries a cut in the interest rate does not simultaneously stimulate capacity utilization; (b) in contrast to previous studies, the results do not show evidence that durable-goods industries are more sensitive to interest rate changes than other industries are; and (c) in many industries, the interest rate and capacity utilization move in the same direction. This suggests that manufacturers initially respond to interest-rate shocks by adjusting the utilization of their current capital stock.

The final chapter of this thesis investigates the impact of the home country's levels of income, civil liberties and political rights on the spillover effects of technical and managerial innovation using pooled mean group estimations in a dynamic heterogeneous panel setting of 60 countries between 1996–2014. The findings show that, for high-income countries, domestic innovations in management are a significant source of change in productivity. In contrast, the results do not support the role of the domestic development of management innovation in middle-income countries. Regardless of which metric is utilized in the analysis, national spillovers of management ideas increase the productivity of countries with the most-liberal democratic regimes. In democratic countries where the regime is only partially liberal, domestic management innovations have a depressing effect on productivity.

To my parents, Mahrokh & Teymour

for their love, inspiration and support.

Acknowledgements

First and foremost, I would like to express my special appreciation and gratitude to my advisor, Professor Hashmat Khan, who has been a tremendous mentor for me. He has supported and encouraged me with his knowledge and patience. He has been a true professional. The work presented in this thesis would not have been possible without his advice and support.

I would also like to thank my committee members, Professors Stanely Winer, Christopher Gunn, and Marcel Voia from Carleton University and Serge Coulombe from University of Ottawa for their helpful comments and support along the way. Many thanks, Stephen Kosempel and Yiagadeesen Samy, external and internal thesis examiners, for their helpful feedbacks. Thank you to Francisco Ruge-Murcia, the editor of CJE, and two anonymous referees for their comments and suggestions on the first paper. I am especially thankful to Professors Stephen Ferris and Minjoon Lee for their generous advices on the second paper.

I am grateful to my fellow classmates and colleagues, especially Sarah Mohan, Charles Saunders and Beatriz Peraza for sharing advice and experiences. Thank you to the Department of Economics' administrative staff, in particular Marge Brooks, Renée Lortie, and Dawn Bjornson, for supporting us over these years.

I am deeply grateful to my parents and my sisters, for their love, support and encouragement along the way. Finally, my deepest gratitude goes to Mostafa Milani, my best friend and amazing husband. Thank you for standing up for me, supporting me, and believing in me.

Table of Contents

List of Tables

List of Figures

Chapter 1

Sources of Canadian Economic Growth

1.1 Introduction

Growth in output per hour in Canada has significantly slowed down since the early 2000s, falling to less than half the average growth of previous two decades (See Figure 1.1). This suggest that the Canadian economy may have drifted away from a long run balanced growth path. A better understanding of the historical sources of Canadian growth can help determine if this decline largely reflects transitional forces such as capital accumulation, human capital, and innovation or whether the economy is already on a new balanced growth path. The traditional growth accounting framework based on Solow (1957) used in previous research is limited in addressing these issues.[1] We, therefore, apply the accounting framework based on modern ideas-oriented growth theory proposed in Jones (2002).[2] The key difference between the two approaches is that the former computes total factor productivity as a residual whereas the latter explains it in terms of underlying economic forces such as ideas-oriented research and development (R&D) and human capital. This framework allows us to separately quantify the contribution of transitional sources and growth along the steady state balanced growth path, which can provide good insights on their relative importance.

The particular version of the modern growth theory that forms the basis of the accounting exercise is a semi-endogenous growth model. In this framework, total factor productivity is endogenous but long-run growth is driven by exogenous population growth (Jones (1995)). This feature offers two specific advantages. First, if the economy is growing along the balanced-growth path, then the model implies that all of growth is driven by exogenous population growth, which reflects growth in the effective number of world researchers generating productive ideas. This aspect allows us to distinguish between transition dynamics and steady-state growth, and quantify the contribution of each to growth. Second, we can also quantify the growth contributions of the forces mentioned above that have an endogenous effect on productivity.

The sample period for our analysis is just over three decades, 1981 to 2014. The start date is dictated by data availability for the empirical analysis. Canadian output

[1]Examples of previous research using the traditional growth accounting framework include Khan and Santos (2001), Kosempel and Carlaw (2003) and Baldwin et al. (2012), among others.

[2]The empirical analysis in Jones (2002) is based on G-5 (France, West Germany, Japan, the United Kingdom, and the United States for 1950-1993 (44 years of data).

per hour grew at an average rate of 1.10 percentage points between 1981 and 2014. We find that nearly 90% of the total average growth rate has been due to transitional factors, and attribute about 10% to steady-state growth driven by population growth. Capital intensity and human capital growth are the largest transitional factors contributing 0.43 and 0.52 percentage points, respectively, of the total average growth rate. Interestingly, excess ideas growth (total ideas growth minus steady state growth) contributed less than 0.05 percentage points to total average growth. Based on these findings, it is likely that the recent growth slowdown reflects the effect of transitional factors rather than a new balanced growth path for the Canadian economy.

Our analysis can inform policy makers on routes to economic growth, especially those which can be influenced by public policy. Since the economic relationship between Canada and the U.S. has always been closely tied, a detailed comparison with the U.S. growth experience over the same period 1981 to 2014 would aid this objective. We, therefore, apply the growth accounting exercise to the U.S. economy over this period and provide a detailed comparison. U.S. output grew at an average of 1.64 percentage points. Our results show that transitional factors have also played a dominant role in the U.S. economy, thus confirming the findings of Fernald and Jones (2014) for this sample period. Over 86% of the growth is contributed by transitional factors. The large transitional sources of growth is a similarly shared in both Canadian and U.S. growth experience. We, however, find that the composition of these transitional factors is markedly different across the two countries in three notable aspects. First, unlike Canada, excess idea growth contributed 1.2 percentage points to average growth in output per hours in the U.S. economy over this period. Second, the total contribution of human capital and excess ideas to U.S. economic growth is substantially higher relative to Canada, about 92% versus 52%, respectively. Among these two transitional factors, human capital is the main driver of the Canadian economy, while in the U.S. excess ideas has played a dominant role. Third, capital accumulation as reflected in capital-output growth has made a large contribution to Canadian economic growth, nearly 40%. By contrast, the contribution of capital-output growth turns out to be negative (-5.35%) over 1981–2014 in the U.S.[3]

Despite the large role of transitional factors in the U.S., the average growth rate of the U.S. output per hour has been relatively stable over 1981–2014. Similarly, in the past 150 years per capita real U.S. GDP has grown at a steady 2% per year (see Jones (2015)). Reconciling this steady growth stylized fact with theories of endogenous growth has been challenging because such theories predict that increases in human-capital investments, and ideas-oriented R&D should have permanent effects on growth rates. Jones (2002) provided an interpretation of this relatively large contribution of transition factors with a stable growth rate by distinguishing between a constant growth path and a balanced-growth path. Under the constant growth path hypothesis, all growth rates are constant but the allocations themselves need not be constant. But unlike a balanced growth path, an economy need not remain on the constant growth path forever. This distinction helps reconcile why growth may appear to be constant (and potentially away from the steady state) if driven by transitional factors.

[3] Fernald and Jones (2014) find that capital-output growth has not contributed to growth over the 1950–2007 period.

Indeed, for Canada, the evidence points to increases in at least one of these two factors, namely human capital growth, over the past decades so it is unlikely that the observed evidence indicates an economy moving along a balanced growth path. Yet, the interpretation that the Canadian economy is moving along constant growth path is not clear cut. To formally investigate this view, we conduct the same test as in Jones (2002). Comparing long-run growth parameter calculated under the constant growth path decomposition with the estimated values shows that the constant growth path hypothesis does not hold for the Canadian economy over the sample period. By contrast, we confirm that this hypothesis continues to hold for the U.S. economy for the same time period as Canada, as found in Fernald and Jones (2014) for the earlier period. To summarize, while the constant growth path assumption continues to be a good approximation of the U.S. growth experience, it is not so for Canada.

Our findings suggest that the recent slowdown in Canadian productivity growth may be tied to the limited role of R&D oriented sources of growth. We find that the elasticity of output per hour with respect to world research effort—the responsiveness of the Canadian economy to ideas—is significantly smaller, nearly 1/10th of that of the U.S. An economy's capacity to absorb new ideas is affected by a host of factors such as regulation, taxation, density of businesses, network effect, subsidization of R&D activities, among others. Lychagin et al. (2016) find that intraregional spillovers in the form of local spillovers are economically important for firm productivity, and can matter for economic growth. It is likely that a combination of these factors might explain why R&D oriented sources have not contributed much to Canadian growth experience.

The remainder of this paper is organized as follows. Section 1.2 describes the modern growth accounting framework. Section 1.3 presents the data and the growth accounting results. Section 1.4 examines the constant growth path hypothesis for Canadian and U.S. economies. Section 1.5 of the paper discusses the gap between the G-6 R&D intensity contribution in output per hour growth between these two economies. Section 1.6 provides a robustness check and section 1.7 concludes.

1.2 A semi-endogenous growth model

The modern ideas-oriented growth accounting framework is based on the semi-endogenous growth theory proposed by Jones (1995) and Jones (2002).[4] Here we briefly describe an overview of the model and provide the key equations underlying the framework that we use in the later sections.

The world consist of J economies that differ in their endowments and allocations. Each economy, however, has the same production function. The only link between the economies is that they all share ideas. Production in each economy occurs using the common and cumulative stock of ideas, country-specific capital stock, and aggregate human capital. Capital stock is accumulated by foregoing consumption, and human capital is accumulated by foregoing time in the labour force. New ideas are created using the current stock of ideas and the effective world research effort. The resource constraint on labour dictates that total labour time (the time endowment of an individual is normalized to one) is divided between producing output, human

[4] See, also, Kortum (1997) and Segerstrom (1998).

capital, and ideas. Each economy is populated by an identical number of infinitely lived agents, and the population grows at a common and constant exogenous rate.

Production function: Output is produced using the production function

$$Y_{jt} = A_t^{\sigma_j} K_{jt}^{\alpha_j} H_{Yjt}^{1-\alpha_j}, \quad \sigma_j > 0,\ 0 < \alpha_j < 1,\ j = 1, ..., J \tag{1.2.1}$$

where Y_{jt} is output in country j, A_t is the common stock of ideas, K_{jt} is capital stock, and H_{Yjt} is the quantity of human capital.

Capital accumulation: New capital is produced via the capital accumulation process given by

$$\dot{K_{jt}} = s_{Kjt} Y_{jt} - d_j K_{jt}, \qquad K_{j0} > 0 \tag{1.2.2}$$

where s_{Kjt} is investment rate and $0 < d_j < 1$ is the depreciation rate in country j.

Human capital accumulation: The process of human capital accumulation is described as

$$H_{Yjt} = h_{jt} L_{Yjt} \tag{1.2.3}$$

$$h_{jt} = e^{\psi_j \ell_{hjt}}, \quad \psi_j > 0 \tag{1.2.4}$$

where h_{jt} is human capital per person, L_{Yjt} is the total labour employed in producing output, and ℓ_{hjt} is the amount of time an individual spends in accumulating human capital. **New ideas creation:** The process of new ideas creation is described as

$$\dot{A}_t = \delta \tilde{H}_{At}^{\lambda} A_t^{\phi}, \qquad A_0 > 0,\ 0 < \lambda \leq 1,\ \phi < 1 \tag{1.2.5}$$

$$\tilde{H}_{At} = \sum_{j=1}^{J} h_{jt}^{\theta} L_{Ajt}, \quad \theta \geq 0 \tag{1.2.6}$$

where δ is a shift parameter, $\tilde{H}_{At}$ is the effective world research effort, and L_{Ajt} is the number of researchers in country j at time t. The parameter restriction $(0 \leq \lambda < 1)$ in (1.2.5) allows for the probability of duplication in research, and whether past discoveries have a positive $(\phi > 0)$ or negative $(\phi < 0)$ effect on current research productivity.

Resource constraints and population growth: The labour force available for new ideas creation and output production is

$$L_{Ajt} + L_{Yjt} = L_{jt} = (1 - \ell_{hjt}) N_{jt} \tag{1.2.7}$$

$$N_{jt} = N_{j0} e^{nt}, \qquad N_{j0} > 0,\ n > 0 \tag{1.2.8}$$

where L_{jt} denotes employment, N_{jt} denotes the number of agents in each economy at time t which grows at a constant exogenous rate $n > 0$.

By re-writing the production function (1.2.1) in terms of output per worker ($y_{jt} \equiv Y_{jt}/L_{jt}$), we can obtain the key expression that forms the basis of the quantitative analysis as follows. We substitute (1.2.3) in (1.2.1), then divide both sides by $Y_{jt}^{\alpha_j}$

and rearrange to express Y_{jt}. We then divide both sides by L_{jt} to get

$$y_{jt} = \left(\frac{K_{jt}}{Y_{jt}}\right)^{\frac{\alpha_j}{1-\alpha_j}} \ell_{Yjt} h_{jt} A_t^{\frac{\sigma_j}{1-\alpha_j}}, \quad \ell_{Yjt} \equiv L_{Yjt}/L_{jt} \tag{1.2.9}$$

where K_{jt}/Y_{jt} is the capital-output ratio, and ℓ_{Yjt} is the fraction of the labour force that produces output. The economy characterized in equations (1.2.1) to (1.2.8) exhibits a stable balanced growth path along with the growth rate of output per worker, g_{yj} is

$$g_{yj} = \gamma_j n, \quad \gamma_j \equiv \frac{\sigma_j \lambda}{(1-\alpha_j)(1-\phi)}. \tag{1.2.10}$$

Equation (1.2.10) shows a key implication of the semi-endogenous growth model that is different from endogenous growth models of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). Although productivity is endogenous, the long run growth rate depends on the exogenous population growth rate.

1.3 Accounting for Canadian growth

We apply the framework described in Section 2 to determine the sources of Canadian economic growth. Specifically, the production function in (1.2.9) forms the basis of the quantitative analysis in this paper. We first describe the data required to implement the accounting growth for Canada.

1.3.1 Data

Figures 1.2–1.10, show the data we use in the quantitative analysis. These data correspond to the variables in equation (1.2.9). We now describe each variable in more detail and also provide information on the parameters in (1.2.9). In order to facilitate a proper Canada–U.S. comparison, we apply the same data sources.

Output per hour

Output per hour is the ratio of real GDP (2011 constant prices) to average annual hours worked.[5] Figure 1.2 shows real GDP per hour (in logs). There has been a slow down in growth after 2000 as evidenced in the flattening of the line. We return to this observation in Section 1.5.

Physical capital

We obtain total physical capital from the Penn World Table 9.0 (PWT 9.0) which includes 4 assets: structures (including residential and non-residential), machinery (including computers, communication equipment and other machinery), transport equipment and other assets (including software, other intellectual property products, and cultivated assets). Figure 1.3 shows that the capital-output ratio (in logs) for Canada and the U.S. slowly declines during the 1990s and then gradually increases during the 2000s. In Canada we observe an increasing trend over 1981–2014. Canada had a lower capital-output ratio till 1989, and since then the ratio has been uniformly

[5]Source: Real GDP is from Penn World Table 9.0.

higher than the that in the U.S.[6]

Human capital per person

OECD defines human capital as the 'productive wealth embodied in labour, skills and knowledge'. Human capital is usually estimated through education measures. Many authors have used formal education measures, like the level of educational attainment or enrolment rates, as a measure of the human capital, while others have employed indirect proxies as a way to identify human capital (Prados de la Escosura and Rosés (2010)). Mankiw et al. (1992) and Klenow and Rodriguez-Clare (1997) employ the secondary school enrolment rate as a measure of investment rate in human capital. They, however, ignore primary and tertiary schooling and attainment of the workforce, which is a source of bias in their measure. Jones (2002) uses years of educational attainment using Bureau of the Census (1996), which includes elementary, high school, and college. In this paper we use two different human capital indices. The first one is from PWT 9.0, which is based on the educational attainment data from Barro and Lee (2013), Cohen and Leker (2014) and the return on education from Psacharopoulos (2014). Cohen and Leker (2014) construct their educational attainment series from the OECD database on educational attainment and from surveys published by UNESCO. They argue that their new estimated series for educational attainment in different countries have higher quality and can be used as a direct substitute for the Barro and Lee (2001) data. In estimation of the second human capital

[6] Figure 1.4 shows share of gross capital formation at current PPPs. After 2006 the gap between the share of gross capital formation in Canada and U.S. is increased. However, it is not a good measure for the comparison, since the share of gross capital formation is based on current PPPs and capital output ratio is based on constant national prices (in mil. 2011US$).

index we use two main factors: educational attainment (years of schooling) and the economic rate of return to schooling.

i. Educational attainment (years of schooling): Since Barro and Lee data are available until 2010 in five-year intervals, we divide the average growth of each interval by five to get annual data. We predict data after 2010 using average growth of educational attainment. Figure 1.5 plots average educational attainment in Canada and U.S. for persons aged 25 and over, from 1981 to 2014. Educational attainment of Canada rises from a low of 9.84 years in 1981 to a high of 12.84 years in 2014. Although during this period Canada consistently experienced a lower level of educational attainment compared to the U.S., it had a higher average growth rate, 0.79% compare to 0.40%.

ii. Economic rate of return to schooling: Equation (1.2.4) is based on the literature of human capital where ψ_j is the economic rate of return to schooling in country j. An additional year of schooling generates $100\psi_j\%$ growth in human capital. We take the estimated values of ψ_j from Trostel et al. (2002). They employed a Mincerian regression model (Mincer (1974)) and IV estimation using International Social Survey Programme Data for the period 1985-1995. This survey contains information about individual earnings, marital status, and education in a sample of employed individuals between 21-59 years old in the year of interview. Their results provide IV estimates for U.S. and Germany using spouse's education as an instrument for education. They also provide Mincerian regression estimates for Canada, Japan and U.K. Mincer (1974) modelled the natural logarithm of income (y_j) as a function of years of schooling (S_j)

and the vector of observed attributes (X_j).[7]

$$y_j = X_j \Phi_j + \psi_j S_j + u_j \tag{1.3.1}$$

For Canada, the estimated returns are 3.8 and 4.5 percent for males and females, respectively, which are approximately half the U.S. equivalent. Trostel et al. (2002) claim that in general IV estimates are over 20 percent higher than OLS estimates. This point suggests that Canada's rate of return to schooling using IV should be approximately 5.4%. Since Trostel et al. (2002) do not estimate economic rate of return to schooling for France, we use the estimated results of Bhatti et al. (2013) who applied two-stage least squares technique in estimation of rate of return to schooling. Coulombe and Tremblay (2006) also measured human capital for Canada by using different indicators, based on university attainment, literacy test scores, and years of schooling. They estimated macroeconomic rate of return of one additional year of education in Canada using IV estimations for period 1951-2001 of approximately 7.3%. They emphasize that their results are consistent with microeconomic Mincerian regression. To apply consistent estimated values for economic rate of return to schooling in accounting exercises, we did not use their results in the growth decomposition. Figure 1.6 shows human capital per worker from PWT 9.0 and estimated

[7] We note two criticisms of the Mincerian regression in estimating the rate of return to schooling. First, Manuelli and Seshadri (2014) estimate rate of return to schooling by entering 3 periods in their estimations: early childhood, schooling period and job training period. They argue that since in Mincerian regression only the schooling period is considered, the rate of return to schooling is consequently underestimated. Second, Belzil and Hansen (2002) show that when the rate of return to schooling is a sequence of spline functions, the relationship between log earnings and schooling is convex while Mincerian equation is based on a linear relationship. For these reasons, Mincerian regression is not a perfect method in the estimation of rate of return to schooling but lack of data prevent us to use another method.

ones (alternatives) using different rates of return to schooling for Canada and the U.S. The increase in human capital per worker during this time is due to the rise in educational attainment. Since in current research, we are looking at average growth rates over the study period, the initial level of human capital would not affect the decomposition results as long as the average growth is the same. PWT 9.0 provides higher human capital indices which are quite close across countries. While when we look at estimated rates of return to schooling from the literature and average years of schooling, we expect lower level of measured human capital. For this reason we use both of the PWT 9.0 and the estimated values in the growth accounting exercise.

Multifactor productivity

Following Jones (2002), we obtain multifactor productivity as a residual from (1.2.9), $A_t^{\sigma_j/(1-\alpha_j)}$. The measured multifactor productivity for Canada does not show any clear upward or downward trend over the entire sample 1981–2014. For the U.S. we see a slight slowdown at the beginning of the sample, but it increases after 1985 (see Figure 1.7).

World research effort

We define R&D merged across the G5 and Canada under the assumption that new ideas are disseminated between economies. In the calculation of world research effort we assume that the G-6 countries are closest to the world technological frontier and contribute the most to creation of new ideas. Specifically, we assume that just G5 countries and Canada are the source of these new ideas. Under the assumption

$h_{jt}^{\theta} = 1$, we require only the total number of R&D researchers to construct the world research effort measure. In the OECD statistics, total R&D personnel includes three groups of employees: researchers, technicians and other support staff. The U.S. data are available only for the number of researchers. For this reason, we just consider total number of researchers in our calculation. Figure 1.8 shows the ratio of country research effort to world research effort using the baseline definition of the world research effort. We present robustness to an expanded measure of the world research effort in Section 1.6.

1.3.2 Growth accounting

Using (1.2.9), we can express the growth rate of output per person between *any two points*, denoted by hat (ˆ), as

$$\hat{y}_{jt} = \frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt}) + \hat{h}_{jt} + \hat{\ell}_{Yjt} + \frac{\sigma_j}{1-\alpha_j}\hat{A}_t \quad (1.3.2)$$

$$= \frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt}) + \hat{h}_{jt} + \hat{\ell}_{Yjt} + \left(\hat{A}_{jt} - \gamma_j \tilde{n}\right) + \gamma_j \tilde{n}, \quad (1.3.3)$$

where $\hat{A}_{jt} \equiv \frac{\sigma_j}{1-\alpha_j}\hat{A}_t$. Equation (1.3.3) adds and subtracts $\gamma_j \tilde{n}$ to highlight that if the economy was growing along the steady state balanced growth path then almost all of the growth should be accounted for by $\gamma_j \tilde{n}$. This result holds since all other hat terms on the right hand side of (1.3.3) are zero along the balanced growth path. Table 1.1 denotes growth rates of variables which we use in constructing the decomposition shown in (1.3.3). As we mentioned earlier in this paper, two different human capital indices are used in this paper. Growth decompositions provided in section 3.3 and 4 use human capital indices from PWT 9.0. The decompositions in the Appendix use our estimated human capital indices as alternatives.

Parameters

To implement growth accounting we also need parameters α_j, σ_j, and γ_j. We assume that Canada's capital share parameter $\alpha_{CAN} = 1/3$. From Fernald and Jones (2014), we take $\alpha_{U.S.}$ to equal to 0.32 which reflects the decline in capital share over recent years. We also relax Jones (2002) assumption that the $(1-\alpha_j) = \sigma_j$. Under this strict assumption the scale effect parameter (γ_j) is the same for all countries. Dividing both sides of production of ideas by A_t and applying $\gamma_j \equiv \frac{\sigma_j \lambda}{(1-\alpha_j)(1-\phi)}$ will give:

$$\frac{\dot{A}_t}{A_t} = \delta \left(\frac{H_{At}}{{A_t}^{\chi_j/\gamma_j}} \right)^{\lambda}, \quad \chi_j = \sigma_j/(1-\alpha_j). \tag{1.3.4}$$

Replacing $A_{jt} \equiv A_t^{\sigma_j/(1-\alpha_j)}$ in (1.3.4) yields:

$$\frac{\dot{A}_{jt}}{A_{jt}} = \delta \left(\frac{H_{At}}{{A_{jt}}^{1/\gamma_j}} \right)^{\lambda}. \tag{1.3.5}$$

By rewriting this equation in discrete format we have:

$$\frac{\Delta A_{jt+1}}{A_{jt}} = \delta \left(\frac{H_{At}}{{A_{jt}}^{1/\gamma_j}} \right)^{\lambda}. \tag{1.3.6}$$

We can also write the log-linearize form of (1.3.6) in terms of multifactor productivity around a path where multifactor productivity and world research effort are growing at a constant rate. The log-linearized form is

$$\Delta A_{jt+1} = c + \lambda g_A(logH_{At} - \frac{1}{\gamma_j}logA_{jt}) + \varepsilon_{t+1}, \tag{1.3.7}$$

where c is a constant and ε_{t+1} is an error term. We impose a reasonable value range for λ between a minimum value of 0.25 and a maximum value of 1.0, and estimate γ_j both with and without this restriction.

Tables 1.2 and 1.3 show the estimation results using specification (1.3.6) for the non-linear model and specification (1.3.7) for the log-linearized model. Estimated results encompass a plausible range from 0.13 to 0.19 for γ_{CAN} and a range from 0.08 to 0.54 for $\gamma_{U.S.}$. We also consider an intermediate value of γ_j for each of these ranges. If productivity growth for each of these countries is not measured accurately and that productivity growth is increased over this period, we should consider the higher value of estimated γ_j. Otherwise, if productivity growth is measured accurately and it has declined over this period and parameter λ is small, we should consider the lower value of estimated γ_j. The standard error of estimations which reflects sampling uncertainty, gives the range of 0.13 to 0.19 for γ_{CAN} and the range of 0.08 to 0.54 for $\gamma_{U.S.}$ that most likely include the true value of γ_j. Using these parameters values and the data from Table 1.1, we can now do decomposition expressed in (1.3.3).

1.3.3 Results

Table 1.4 and 1.5 show the growth accounting results for Canada and U.S., respectively. First, the contribution of capital-output ratio in Canada is 0.43 percentage points or about 39% of the total average growth in output per worker. By contrast, capital intensity has a small and negative contribution to U.S. growth. It shows the role of capital accumulation, the key mechanism in standard neoclassical growth theory, has been quite limited in U.S. economy while in Canada it remains a significant source of growth. The contribution of labour reallocation from producing goods to creating new ideas is very smaller and negative (about -0.01 percentage points) in both countries.

Second, increased human capital contributed nearly half a percentage point or about 47% of the growth in output per worker over the sample period. The contribution of human capital in U.S. growth is less than half of that in Canada. This suggests that human capital accumulation over the past three decades has had an important influence on long-run growth in Canada while it has played only moderate role in U.S. growth.

Third, less than 15% of the growth rate of output per hour of Canada is attributed to the stock of ideas produced by researchers in the G-6 countries. By contrast, the largest share of U.S. output growth is due to the increase in the stock of ideas produced by researchers in the G-6 countries, accounting for 1.43 percentage points or over 86% of the growth rate of output per hour. This effect is itself the sum of the steady state component and growth in the stock of ideas in excess of the steady state. Doing the decomposition allows us to separate out the relative contribution of these two effects. The component of steady state growth itself is over 0.11 percentage points of output per hour. This share is attributed to the growth in effective number of world employment which is in turn driven by population growth (the scale effect). For the different values of γ_{CAN}, this steady state contribution ranges between 0.10 to 0.14 percentage points (i.e. under 14% of the total average growth in output per worker). For the U.S. economy approximately 0.06 to 0.41 percentage points (i.e. under 25% of the total average growth in output per worker) is attributed to the scale effect. Excess idea growth for Canada is around 0.05 percentage points (or 4.46% of the growth in output per worker). Depending upon the values of γ_{CAN}, the share ranges from 0.02 to 0.06 percentage points while for the U.S. economy it is between 1.02 and 1.37 percentage points.

We summarize the three main points in our findings. First, both Canadian and U.S. economies are not on a balanced growth path implied by the semi-endogenous growth theory. Second, the contributions of human capital and stock of ideas to growth differ substantially across Canada and the U.S. The share of human capital in the average Canadian growth experience over the past 34 years is over 47% whereas the share due to the dissemination of the stock of ideas produced in G-6 countries is under 5%. By contrast, in the U.S. the shares of these two factors are approximately 19% and 74%, respectively. Third, the contribution of capital intensity is substantial in Canada whereas it has a slightly negative contribution to the U.S. growth experience.

Based on our findings, the recent slowdown in growth shown in Figure 1.1 is likely due to transitional factors rather than a new balanced growth path for the Canadian economy.

To have a better understanding of slow down of Canadian growth in last decade compare to previous two decades, we compare decomposition for these two periods.

Table 1.6 shows the growth accounting results for Canada over 1981–2002 and 2003–2014. Having short time series does not allow us to estimate parameter gamma as we did in previous decompositions. For this reason, we can not separate the scale effect from TFP growth. The growth accounting decomposition corresponds to equation 1.3.2. First, the contribution of the capital-output ratio over 1981–2002 is 0.32 percentage points or about 23% of the total average growth in output per worker. However, the contribution of capital intensity is very high over 2003–2014. The contribution of labour reallocation from producing goods to creating new ideas is quite similar over these two periods. Second, the share of human capital in the average Canadian growth experience over last decade is over 60% whereas the share is under 44% over previous two decades. Third, almost 32% of the growth rate of output per hour of Canada over 1981–2002 is attributed to TFP. However, TFP has a negative contribution to Canadian growth over last decade.

1.4 Does the constant growth path hypothesis hold for Canada?

Despite the large role of transitional factors in the U.S., the average growth rate of the U.S. output per hour has been relatively stable over 1981–2014. Jones (2002) has proposed the constant growth path (CGP) hypothesis to reconcile the large contribution of accounted for by human capital and stock of ideas to U.S. economic growth with the observed steady growth. Is the CGP hypothesis appropriate for describing

Canadian economy over the last 34 years? The evidence is not clear cut. As evident from Figure 1.10, we observe a relatively constant growth in the first two decades of the sample but a slowdown in Canadian growth over the last decade. We, therefore, conduct a formal analysis to examine the CGP hypothesis.

The key expression for the production function that forms the basis of the CGP quantitative analysis is

$$y_{jt} = \left(\frac{K_{jt}}{Y_{jt}}\right)^{\frac{\alpha_j}{1-\alpha_j}} \ell_{Y_{jt}} e^{\psi_j \ell_{h_{jt}}} \nu_j \tilde{\ell}_{A,t}^{\gamma_j} \tilde{L}_t^{\gamma_j}, \tag{1.4.1}$$

where $\nu_j = (\delta_j / g_A)^{\gamma_j/\lambda}$, g_A is the constant growth rate of A, and tilde ($\tilde{}$) denotes the aggregate for G-5 plus Canada. An assumption underlying equation (1.4.1) is that the skill level of the researchers in G-5 plus Canada is the same (h_j must be constant along balanced growth path). Therefore, the weights $h_{jt}^{\theta} = 1$ in equation (1.2.6) will be equal to one. This assumption gives that $\tilde{H}_{At} = \sum_{j=1}^{6} L_{Ajt} = \tilde{L}_{At} = \frac{\tilde{L}_{At}}{\tilde{L}_t}\tilde{L}_t = \tilde{\ell}_{At}\tilde{L}_t$, where $\tilde{L}$ and $\tilde{\ell}_A$ are the G-5 plus Canada employment and merged research intensity, respectively. We define merged research intensity as the ratio of researchers engaged in R&D times one hundred divided by the total number of employment. The constant growth path is defined as a situation in which all growth is constant. A constant growth rate of output per worker can arise, for example, if each of the terms in equation (1.4.1) are growing at a constant rate. Unlike a balanced growth path, however, it does not represent a perpetual situation. We log-difference equation

(1.4.1) and express the growth rate of output as

$$g_{y_{jt}} = \frac{\alpha_j}{1-\alpha_j} g_{k_{jt}} + g_{\ell_{Y_{jt}}} + \psi_j \Delta \ell_{h_{jt}} + \gamma_j g_{\tilde{\ell}_A} + \gamma_j \tilde{n}, \tag{1.4.2}$$

where the g_z denotes the constant growth rate of a particular variable z. We impose Jones (2002) assumption implying researchers have same skill level in G-5 plus Canada. This assumption means that the quality of human capital in the frontier countries (G5 plus Canada) are approximately similar. In Section 5 we discuss a decomposition where this assumption is not imposed. Finally, we obtain parameter γ_j upon dividing growth rate of multifactor productivity by the growth rate of world research effort. This value of γ_j makes the CGP equation (1.4.2) hold with equality, and gives γ_{CAN}=0.057 and $\gamma_{U.S}$=0.502.

1.4.1 Results

Table 1.7 presents the results. We find that transitional factors (human capital growth and G-6 R&D intensity) account for nearly 58% of the Canadian growth in output per hour over the 1981–2014 period. That is, 0.64 percentage points of the 1.10 percentage point growth over 1981–2014. The compositional share of human capital growth and G-6 R&D intensity is 81% and 19%, respectively. Although these compositional shares vary somewhat depending upon the assumptions about human capital indices which are used and the model parameters (see Appendix A.1), the total contribution of human capital and G-6 R&D intensity remains around 58%. Population growth of countries generating ideas contributes less than 4% in Canadian economic growth.

Finally, the contribution of capital accumulation as in the neoclassical growth model is a little over 39%. Second part of Table 1.7 shows the results of U.S. CGP decomposition. We find that the contribution of human capital and G-6 R&D intensity to U.S. economic growth is much higher than Canada, 83.03% versus 58.11%. On the other hand, the contribution of capital accumulation, as reflected in capital-output growth, is relatively higher in Canada. In fact, in the U.S. the contribution of capital-output growth turns out to be negative (-5.35%), whereas in Canada it is about 39%.[8] Our results show when we impose the constant growth path assumptions the contribution of steady state growth in Canadian economy is quite lower.

By looking at the CGP decomposition results we note that the value of $\gamma_{U.S.}$=0.502 for which (1.4.2) holds with equality belongs to estimated econometric range for $\gamma_{U.S.}$ that we reported in Section 1.3.2. This finding shows, therefore, the assumption that U.S. economy is close to its constant growth path was indeed a correct one. The value γ_{CAN}=0.057, however, does not belong to the estimated range (from Section 1.3.2, $0.13 \leq \gamma_j \leq 0.19$). This finding confirms that the CGP hypothesis does not accurately describes the Canadian growth experiences over the last 34 years.

1.5 Discussion

Although we assumed that ideas are common among economies, our results reveal that there is a considerable gap between the G-6 R&D intensity contribution in out-

[8] Fernald and Jones (2014) find that capital-output growth did not contribute to growth over the 1950–2007 period. There are three main reasons why our results for U.S. differ somewhat from theirs. First, the time period is different. Second, our decomposition is based on G-6 countries while theirs is based on G5 countries. Third, they used the BLS measure of labour composition which grows more slowly.

put per hour growth for Canada and the U.S. What might there be the reasons behind the gap in γ_j? From (1.4.1), γ_j is the elasticity of output per hour respect to world research effort which shows how each economy responds to these new ideas. Our results show that the responsiveness of Canadian economy to ideas is almost 1/10th of that in the U.S. ($\gamma_{CAN}/\gamma_{U.S.} \approx 0.11$). The ability of each economy in absorbing of new ideas can be resulted from regulation, taxation, density of businesses, network effect, and subsidization of R&D activities. Lychagin et al. (2016) find that intraregional spillovers in the form of local spillovers are economically important for firm productivity. They suggest that such spillovers matter for social learning and capitalization of complementarities among firms research activities, and can be important factors for economic growth. It is likely that a combination of these factors might explain why R&D oriented sources have not contributed much to Canadian growth experience.

1.6 Robustness to an alternative measure of world research effort

In the accounting exercise we imposed the same restriction as in Jones (2002) that weights (skill level of researchers) are the same ($h^{\theta}_{jt} = 1$) implying that G-6 R&D intensity component ($\gamma_j g_{\tilde{\ell}_A}$) in (1.4.2) depends only on the growth of the fraction of labour force employed in research at the G-6 level and parameter γ_j. Under this restriction all the cross-country difference in G-6 R&D intensity come from differences in γ_j. It is certainly possible, for example, that both differences in skill levels and a country's spending on R&D relative to GDP are also relevant for the total research effort. Therefore, an alternative way to define the world research effort would be

$$\tilde{H}_{At} = \sum_{j=1}^{J} h_{jt} E_{Ajt} L_{Ajt}, \tag{1.6.1}$$

where E_{Ajt} denotes the amount of R&D spending per researcher. While (1.6.1) is a plausible generalization of (1.2.6), it does not permit a separation of the long run source of growth from transitional factors which is the main concern in decomposition.

Despite this implementation issue, we consider the alternative measure as a proxy for the world research effort. We need three groups of data to calculate this alternative measure world research effort to implement the robustness check: human capital per employee, number of R&D researchers, and average R&D spending for per researcher. We have already discussed human capital per person and the number of R&D researchers in Section 1.3.1. The R&D expenditure data are available since 1981 for G5 and Canada countries except U.S. Figure 1.9 plots the ratio of the country research effort to the world research effort based on modified world research effort definition which includes R&D expenditure and cross country differences in quality of human capital. As Figure 1.9 shows, there is a large gap between the U.S. and the Canadian shares of the world research effort. Canada contributes less than 5% of the world research effort which is quite constant over this period, whereas U.S. accounts for over 50% of the world research effort. It turns out that the average growth rate of each country's share is quite similar under both baseline and modified definitions of the world research effort (see Figures 1.8 and 1.9). This is the reason why the modified definition of the world research effort still gives similar result as in the baseline. Estimated γ_j using the modified definition of world research effort in specifications (1.3.6) and (1.3.7), ranges from a low value of about 0.13 to a high value of about 0.17 for Canadian economy. For the U.S. estimated parameter ranges from 0.07 to 0.48. The ranges of estimated γ_j are quite similar under both definitions of the world research effort which support our decomposition results under same skill level assumption ($h_{jt}^{\theta} = 1$).

1.7 Conclusion

Using the modern ideas-oriented growth accounting framework of Jones (2002), we conduct an accounting exercise to determine the sources of Canadian economic growth over the 1981–2014 period. This framework allows us to distinguish between transition dynamics and steady-state growth, and quantify their respective contributions. To put the Canadian growth experience in perspective, we also provide a detailed comparison with the U.S.

We find that almost 90% of the total average Canadian growth rate of output per hour of 1.1 percentage points has been due to transitional factors, mainly capital intensity and domestic human capital growth driven by educational attainment. The growth in excess ideas (total ideas growth minus steady state growth) has contributed a small share of 0.05 percentage points suggesting a limited role.

There are two striking differences between the Canadian and U.S. growth experiences over the sample period. First, over a full percentage point of the average U.S. growth of 1.64 is due to excess ideas whereas this component contributes a small share in Canadian growth. Second, despite large sources of transitional growth in both countries, the 'constant growth view' that is a good assumption to describe U.S. growth is not supported in Canada. We estimate a relatively small elasticity of Canadian output with respect to world research effort. This finding might help understand why there is only a limited role of R&D oriented sources of Canadian growth. Understanding the factors behind the low estimated elasticity of output with respect to ideas is an important direction for future research.

References

Aghion, P. and Howitt, P.: 1992, A model of growth through creative destruction, *Econometrica* **60**(2), 323–51.

Baldwin, J. R., Gu, W. and Macdonald, R.: 2012, Intangible capital and productivity growth in canada, *The Canadian Productivity Review, Published by authority of the Minister responsible for Statistics Canada* .

Barro, R. J. and Lee, J. W.: 2001, International data on educational attainment: Updates and implications, *Oxford Economic Papers* **3**, 541–563.

Barro, R. J. and Lee, J. W.: 2013, A new data set of educational attainment in the world, 1950-2010, *Journal of Development Economics* **104**, 184–198.

Belzil, C. and Hansen, J.: 2002, Unobserved ability and the return to schooling, *Econometrica* **70**(5), 2075–2091.

Bhatti, S. H., Bourdon, J. and Aslam, M.: 2013, Economic returns to education in France: OLS and instrumental variable estimations, *The Lahore Journal of Economics* **18**(2), 51–63.

Cohen, D. and Leker, L.: 2014, Health and education: Another look with the proper data, number 9940 in *CEPR Discussion Papers*.

Coulombe, S. and Tremblay, J.-F.: 2006, Human capital and Canadian provincial standards of living, *Statistique Canada Catalogue* (no. 89-552-mpe-14).

Fernald, J. G. and Jones, C. I.: 2014, The future of U.S. economic growth, *American Economic Review* **104**(5), 44–49.

Grossman, G. M. and Helpman, E.: 1991, *Innovation and growth in the global economy.*, Cambridge, MA: MIT Press.

Jones, C. I.: 1995, R&D-based models of economic growth, *Journal of Political Economy* **103**(4), 759–784.

Jones, C. I.: 2002, Sources of U.S. economic growth in a world of ideas, *American Economic Review* **92**(1), 220–239.

Jones, C. I.: 2015, The facts of economic growth, *NBER working paper 21142*.

Khan, H. and Santos, M.: 2001, Contribution of ICT use to output and labour-productivity growth in Canada, *Bank of canada working paper 2002-7*, Bank of Canada.

Klenow, P. J. and Rodriguez-Clare, A.: 1997, *NBER Macroeconomics Annual*, Vol. 12, National Bureau of Economic Research, Inc, chapter The Neoclassical Revival in Growth Economics: Has It Gone Too Far?, pp. 73–114.

Kortum, S. S.: 1997, Research, patenting, and technological change, *Econometrica* **65**(6), 1389–1419.

Kosempel, S. and Carlaw, K.: 2003, Accounting for Canada's economic growth, *Journal of Economic Development* **28**(2), 83–101.

Lychagin, S., Pinkse, J., Slade, M. and Reenen, J. V.: 2016, Spillovers in space: Does geography matter?, *Journal of Industrial Economics* **LXIV**(2), 295–335.

Mankiw, N. G., Romer, D. and Weil, D. N.: 1992, A contribution to the empirics of economic growth, *The Quarterly Journal of Economics* **107**(2), 407–437.

Manuelli, R. E. and Seshadri, A.: 2014, Human capital and the wealth of nations, *American Economic Review* **104**(9), 2736–2762.

Mincer, J. A.: 1974, *Schooling, Experience and Earnings*, New York: Columbia University Press.

Prados de la Escosura, L. and Rosés, J. R.: 2010, Human capital and economic growth in Spain, 1850-2000, *Explorations in Economic History* **47**, 520–532.

Psacharopoulos, G.: 2014, Returns to investment in education: A global update, *World Development* **22**(9), 1325–1343.

Romer, P. M.: 1990, Endogenous technological change, *Journal of Political Economy* **98**(5), S71–S102.

Segerstrom, P. S.: 1998, Endogenous growth without scale effects, *American Economic Review* **88**, 1290–310.

Solow, R. M.: 1957, Technical change and the aggregate production function, *The Review of Economics and Statistics* **39**(3), 312–320.

Trostel, P., Walker, I. and Woolley, P.: 2002, Estimates of the economic return to schooling for 28 countries, *Labour Economics* **9**, 1–16.

Table 1.1: Average annual growth rates Canada vs. U.S. - comparison, 1981-2014

Growth rate of	Variable	Sample Value Canada	Sample Value U.S.	G-5 + Canada
Output per hour	$\hat{y}$	1.098	1.644	
Capital-output ratio	$\hat{K} - \hat{Y}$	0.866	-0.187	
Share of labour in goods production	$\hat{l}_Y$	-0.016	-0.012	
Human capital	$\hat{h}$	0.493	0.512	
		0.519 (PWT)	0.316 (PWT)	
Multifactor productivity	$\hat{A}$	0.188	1.232	
		0.162 (PWT)	1.428 (PWT)	
World research effort (baseline)	$\hat{\tilde{H}}_A$			2.853
G-5 + Canada labour force	$\tilde{n}$			0.755

Notes: The Sample Value is in percentage points. The values with (PWT) are calculated using PWT 9.0 human capital indices. Tilde ($\tilde{}$) denotes the aggregate for G-5 plus Canada.

Table 1.2: Estimating γ_{CAN}, 1981-2014

	Specification			
Parameter	(1)	(2)	(3)	(4)
		Log Linearized Model		
λ		1.00	0.5	0.25
		-	-	-
$1/\gamma$		7.471	7.240	6.779
		(0.021)	(0.020)	(0.019)
γ		0.134	0.138	0.147
R^2		0.75	0.97	0.99
		Nonlinear Least Square		
λ		1.00	0.5	0.25
		-	-	-
$1/\gamma$		5.379		
		(3.195)		
γ		0.185		

Notes: Robust standard errors are in parentheses. In specifications (2) through (4), specific values of λ are imposed. Only significant coefficients are reported.

Table 1.3: Estimating $\gamma_{U.S.}$, 1981-2014

	Specification			
Parameter	(1)	(2)	(3)	(4)
		Log Linearized Model		
λ	0.040	1.00	0.5	0.25
	(0.001)	-	-	-
$1/\gamma$	1.854			6.377
	(0.147)			(0.85)
γ	0.539			0.157
R^2	0.99			0.7
		Nonlinear Least Square		
λ		1.00	0.5	0.25
		-	-	-
$1/\gamma$		4.385	3.538	3.115
		(1.225)	(1.225)	(1.225)
γ		0.215	0.141	0.080

Notes: Robust standard errors are in parentheses. In specifications (2) through (4), specific values of λ are imposed. Only significant coefficients are reported.

Table 1.4: Accounting for Canada Growth, 1981-2014

		TRANSITION DYNAMICS				
	Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	Excess Idea Growth	Steady-State Growth
γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_{jt} - \gamma_j \tilde{n}$	$\gamma_j \tilde{n}$
0.13	1.098	0.433	-0.016	0.519	0.064	0.098
	(100%)	(39.44%)	(-1.46%)	(47.27%)	(5.83%)	(8.92%)
0.15	**1.098**	**0.433**	**-0.016**	**0.519**	**0.049**	**0.113**
	(100%)	**(39.44%)**	**(-1.46%)**	**(47.27%)**	**(4.46%)**	**(10.29%)**
0.19	1.098	0.433	-0.016	0.519	0.019	0.143
	(100%)	(39.44%)	(-1.46%)	(47.27%)	(1.73%)	(13.02%)

Notes: This table reports the growth accounting decomposition corresponding to equation (1.3.3). The numbers in columns 2-7 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

The baseline results are shown in bold.

Table 1.5: Accounting for U.S. Growth, 1981-2014

		TRANSITION DYNAMICS				
	Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	Excess Idea Growth	Steady-State Growth
γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt}-\hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_{jt}-\gamma_j\tilde{n}$	$\gamma_j\tilde{n}$
0.08	1.644	−0.088	−0.012	0.316	1.368	0.060
	(100%)	(−5.35%)	(−0.73%)	(19.22%)	(83.21%)	(3.65%)
0.30	**1.644**	**−0.088**	**−0.012**	**0.316**	**1.202**	**0.226**
	(100%)	**(−5.35%)**	**(−0.73%)**	**(19.22%)**	**(73.11%)**	**(13.75%)**
0.54	1.644	−0.088	−0.012	0.316	1.020	0.408
	(100%)	(−5.35%)	(−0.73%)	(19.22%)	(62.04%)	(24.82%)

Notes: This table reports the growth accounting decomposition corresponding to equation (1.3.3). The numbers in columns 2-7 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

The baseline results are shown in bold.

Table 1.6: Accounting for Canada Growth, 1981-2002 and 2003-2014

		TRANSITION DYNAMICS			
	Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	TFP Growth
Period	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_{jt}$
1981-2002	1.409	0.325	-0.019	0.618	0.485
	(100%)	(23.07%)	(-1.35%)	(43.86%)	(34.42%)
2003-2014	0.575	0.653	-0.010	0.348	-0.416
	(100%)	(113.57%)	(-1.739%)	(60.522%)	(-72.35%)

Notes: This table reports the growth accounting decomposition corresponding to equation (1.3.3). The numbers in columns 2-7 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

The baseline results are shown in bold.

Table 1.7: Constant growth path decomposition: Canada versus U.S., 1981-2014

			TRANSITION DYNAMICS				
		Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	G-6 R&D Intensity	Scale Effect of G-6 Labour Force
Country	γ_j	$g_{y_{jt}}$	$\frac{\alpha_j}{1-\alpha_j} g_{kjt}$	$g_{\ell_{Y_{jt}}}$	$\psi \Delta \ell_{h_{jt}}$	$\gamma_j g_{\tilde{\ell}_A}$	$\gamma_j \tilde{n}$
Canada	0.05698	1.098	0.433	-0.016	0.519	0.119	0.043
		(100%)	(39.44%)	(-1.46%)	(47.27%)	(10.84%)	(3.91%)
U.S.	0.50229	1.644	-0.088	-0.012	0.316	1.049	0.379
		(100%)	(-5.35%)	(-0.73%)	(19.22%)	(63.81%)	(23.05%)

Notes: G-6 is defined as G-5 plus Canada.

Figure 1.1: Canada: Average growth in real GDP per hour

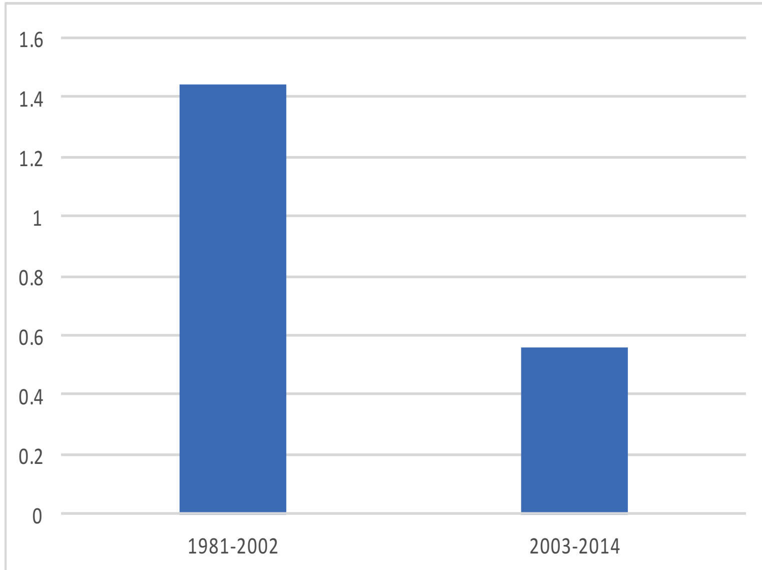


Figure 1.2: Canada: Real GDP per hour

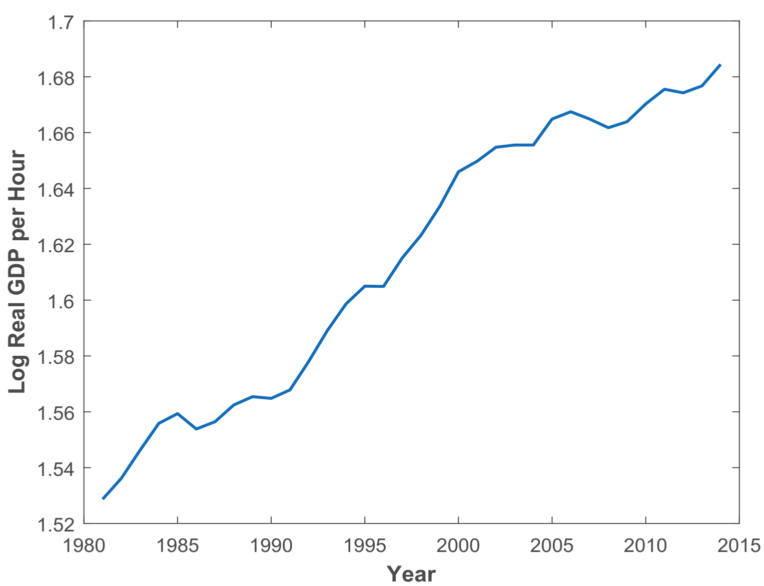


Figure 1.3: Capital-output ratio

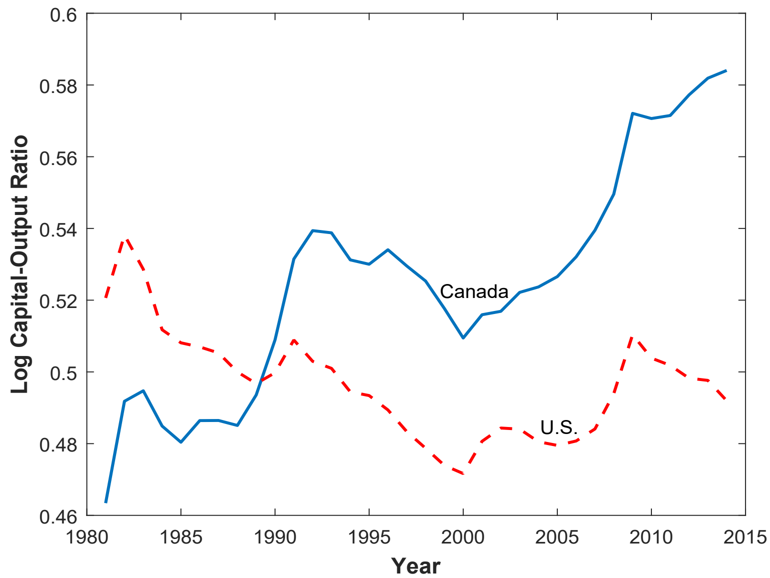


Figure 1.4: Share of gross capital formation

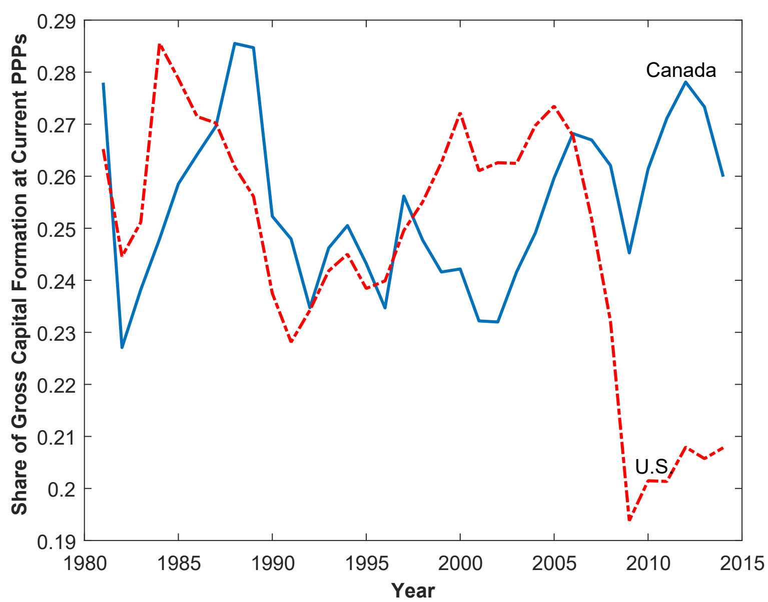


Figure 1.5: Average educational attainment (aged 25 and over)

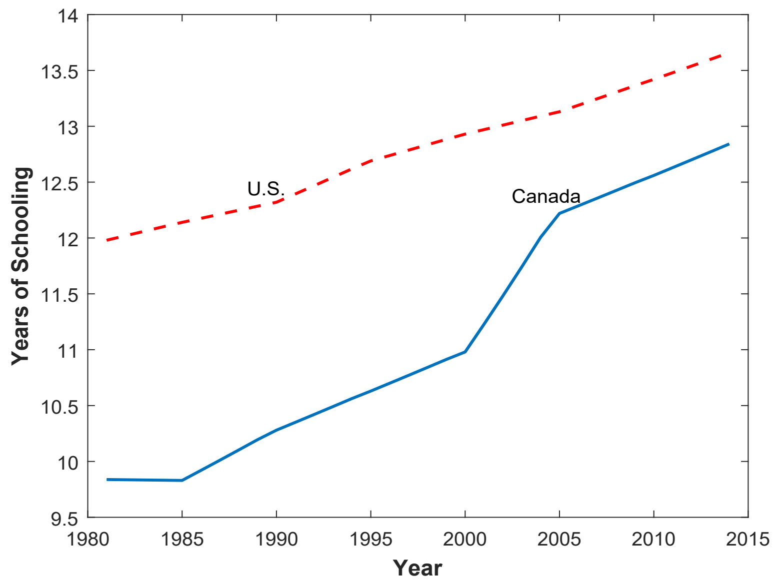


Figure 1.6: Human capital per worker using different rates of return to schooling

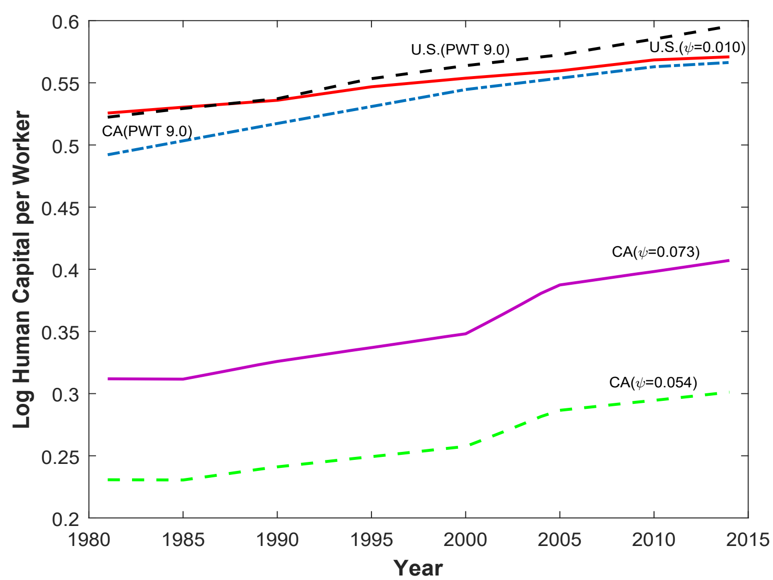


Figure 1.7: Multifactor productivity per hour

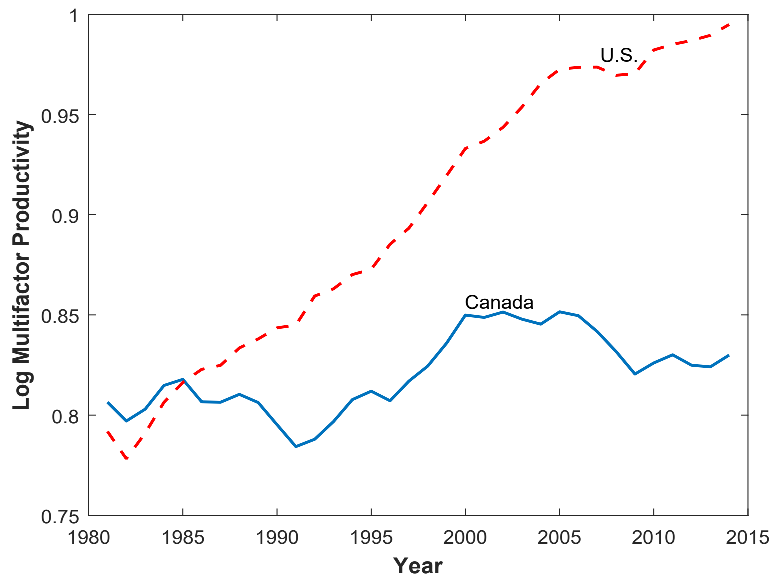


Figure 1.8: Country share in world research effort (baseline)

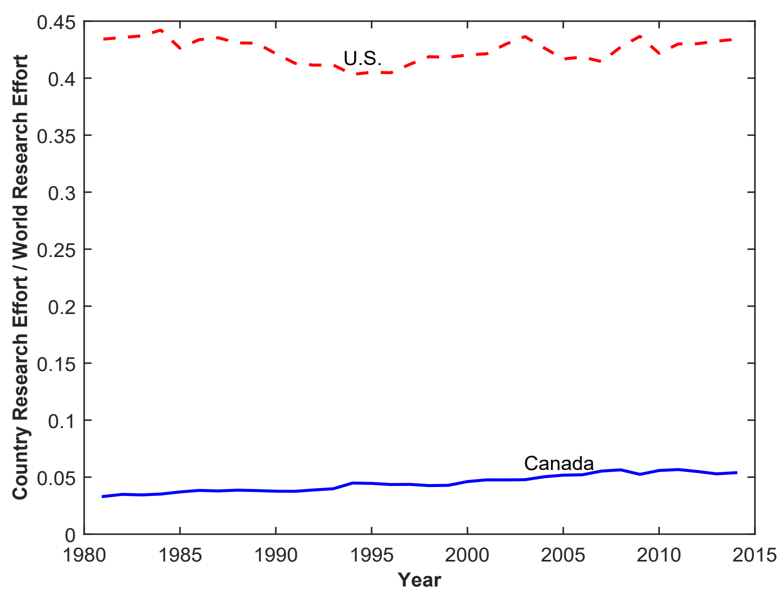


Figure 1.9: Country share in world research effort (robustness)

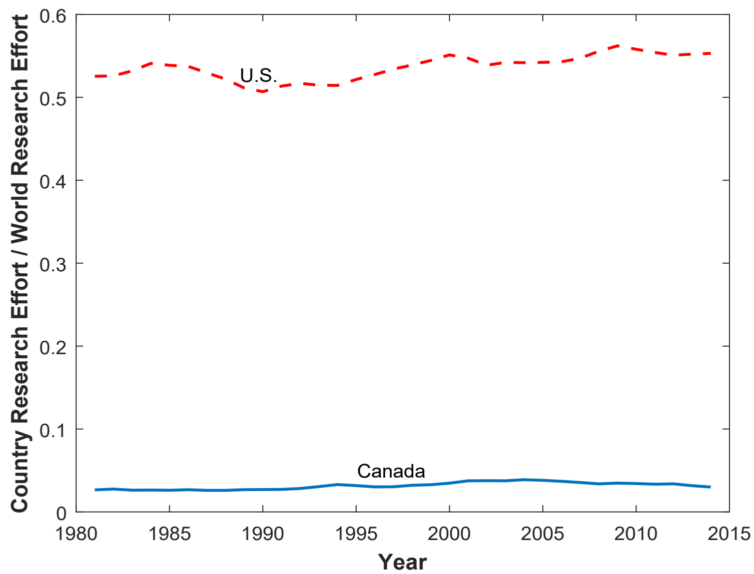
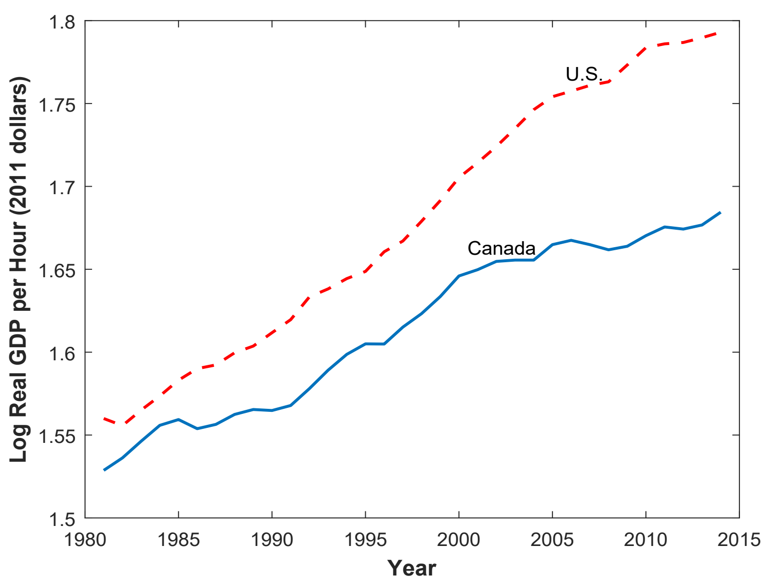


Figure 1.10: Real GDP per hour



Chapter 2

Dissemination of Two Faces of Knowledge: Do Liberal-Democracy and Income-Level Matter?

2.1 Introduction

In analysing productivity, researchers have been using scientific publications to measure the stock of knowledge, for almost three decades. Adams (1990) was the first to use this proxy to show the significant contribution technical knowledge makes to growth in total factor productivity (TFP), in US manufacturing industries, over the period 1953 to 1980. Chen and Dahlman (2004) used the annual number of scientific and technical journal articles published by the residents of specific countries to show the significant effect of the scientific and technical knowledge imparted by these papers on the growth rates of these specific countries' total output. Over the years, researchers have used different indicators to measure the stock of knowledge and to investigate the effectiveness of innovation or new-technical-knowledge generation on productivity growth. These indicators include the number of registered patents, expenditures on research and development, the number of scientists engaged in research and development, and the number of new titles in technology-related publications (manuals, handbooks, and the like).[1] For various reasons, however, all of these measures are flawed.

R&D expenditures allow countries to hire researchers to work on and generate new ideas, but it is innovation that spurs productivity growth. It takes more than two years for a new idea (innovation) to move from a concept to an invention and, ultimately, to a patent application. Although acquiring a patent is one step beyond publication, the use of patent data to measure the level of innovative activity (idea generation) is not without its problems. The most obvious limitation is that not all inventions are patented, which means patents do not capture all innovations. For instance, managerial ideas (such as, team structure, quality-control initiatives, managerial leadership, etc.) that have an impact on productivity do not appear in the form of a patent (Alexopoulos and Tombe (2012)). Another reason for an innovation not being patented is that not all inventions meet the criteria set out by the United States Patent and Trademark Office (USPTO). The other reason inventions are not patented is simply because the inventor did not apply for a patent, and, instead, may have decided to rely on secrecy to prevent duplication of the invention by competitors

[1] For example, see Griffith et al. (2004), Guellec and de la Potterie (2004), Lach (1995), Pessoa (2005), Porter and Stern (2000), and Abdih and Joutz (2006).

(like many tech army innovations) (Chen and Dahlman (2004)). For these reasons, patents are not a precise measure of innovative activity. Furthermore, even after an idea is registered as a patent, in the short run it would not be available and usable by other economies.

To solve the problem of measuring ideas, Alexopoulos and Cohen (2009) used catalogue of the Library of Congress on the number of new technology titles (manuals, handbooks, and the like) that are published in the US. The most obvious limitation of this indicator is that not all books are published in the US. Hence, this measure would not be applicable in the case of cross-country studies. In reality, there is a long process involved in developing an idea and then publishing it in the format of a manual or book. Researchers disseminate their ideas by presenting them at conferences and publishing them in conference papers and journals, which I consider a prior step to publishing a book. Scientific papers that are published in journals do not face the limitations of patents or books. Rather, they are immediately available for use by entities in any other economy around the world, which is the main assumption of the semi-endogenous growth model used in this study.

Due to their ease of availability, I expect scientific publications to have higher international spillover effects, compared to patents and books. This premise leads to the following questions. Does a change in the stock of knowledge in one country affect other countries? Do spillovers of new ideas have effects on the income level of the destination country? Do both the level of civil liberties and the extent of political rights in the destination country influence the absorptive capacity of international ideas?

The main objective of the present paper is to contribute to the empirical understanding of economic growth by estimating and analysing the effect of intra-national and international spillovers of new ideas on productivity. To evaluate the drivers of countries' productivity, I separate the stock of domestic knowledge from the pool of world knowledge. I evaluate the relative importance of intranational versus international knowledge spillovers in fostering TFP. I do so by separately considering the multiple sources of knowledge for each country's ideas production function.

This paper draws on an extensive body of work that uses the number of scientific publications as a measure of innovative output. It then compares this to the number of patents as a measure of innovation. I also distinguish between technical and managerial knowledge to investigate how different types of knowledge contribute to the growth rate of total factor productivity. In contrast to previous studies, which applied neoclassical growth theory to examine the drivers of total factor productivity, I use the semi-endogenous growth model originally introduced by Jones (2002). This model allows me to include the impact of human capital in estimations of total factor productivity. I also control for differences in the number of hours worked in each country. Another contribution of this paper is an adjustment for the share of capital of less developed countries. This provides more precise estimations of total factor productivity for the outlier countries.

In this paper, I adopt pooled mean group (PMG) estimator introduced by Pesaran et al. (1999). This estimator enabled me to examine both the long- and short-run effects of knowledge dissemination on growth in TFP. Using this model allows me to take into account country-specific heterogeneity. I consider 60 countries whose classifications are based on their income level and level of democracy. Although there is a large body of literature that investigates the link between knowledge dissemination and TFP growth, there is hardly any research that focuses on less-developed countries, or countries with less liberal-democratic regimes. This research will contribute to an understanding of how economic and political differences affect intranational and international spillovers of technical and managerial knowledge.

Regardless of which metric is utilized in the analysis, national spillovers of the stock of ideas increase the TFP of high-income countries. The results show that managerial advances have almost three times the impact on the productivity of high-income countries than that of technical ideas. For middle-income countries, however, I find that domestic spillovers of managerial ideas do not contribute to TFP. However, international spillovers of all of the metrics used in this study show a positive impact on the TFP of middle-income countries. For the countries that are the most-liberal-democratic, the impact of managerial innovations on TFP is still positive. However, this effect was reduced, over the period under review, compared to the results of the estimations for high-income countries. Here, it is possible because not all countries with the highest level of liberal-democracy are among the high-income countries. The impact of intranational and international managerial knowledge on the TFP of partially liberal-democratic countries is the reverse. In these countries, national innovations in management show a negative impact on TFP in the long run, while international innovations show a positive effect. From an estimation of the new-ideas-production function, I find that the research production of both technical and managerial ideas increases as the total stock of these ideas increases. Yet, the expansion in the number of researchers has no effect on the flow of managerial ideas.

The remainder of this paper is structured as follows. Section 2.2 presents the theoretical framework for productivity analysis. Section 2.3 presents and discusses the metric, which is the number of ideas found in scientific publications. Section 2.4 describes the econometrics specifications. Section 2.5 provides an empirical analysis including data description and the results based on the different classifications for the countries in the study. Section 2.6 analyses the effect of the stock of ideas on innovation. Section 2.7 concludes.

2.2 Framework for total factor productivity

The theoretical framework of the analysis of TFP, for the purposes of this investigation, uses the semi-endogenous growth model introduced by Jones (1995) and Jones (2002). Although Penn World Table (PWT) 9.0 provides TFP data for many countries, several developing countries emerge as outliers with TFP measurements that are high relative to that of the US. This does not look reasonable. For example, the TFPs of Turkey and Gabon are very similar to that of the US. Also, İmrohoroğlu and Üngör (2016) criticize the reliability of the TFP levels reported in PWT 9.0. They believe the problem arises from considering that the capital share is the same ($\alpha_i = 1/3$) for all countries. To produce more reasonable estimates of the TFP levels, they suggest a simple modification that uses a constant capital share of one third for developed countries and one half for developing countries. Since the TFP levels provided in PWT 9.0 are not accurate for developing countries, I use the semi-endogenous growth model introduced by Jones (1995) and Jones (2002) and I modify the capital share for developing countries so as to estimate the TFP per hour worked. Using the semi-endogenous growth model, I consider the differences in the quality of human capital, which most previous studies ignore.

Assume a world that consists of I economies, where each has the same production possibility but different endowments and allocations. Ideas are the only link between these economies. This means that any new ideas that are created, at any point in time, in any part of the world, will be immediately available for use by other economies. This is a reasonable assumption, since I consider scientific publications as a measure of the new ideas that are available for all economies, after they are published. Output is produced by using the production function

$$Y_{it} = A_t^{\sigma_i} K_{it}^{\alpha_i} H_{Yit}^{1-\alpha_i}, \quad \sigma_i > 0, \; \alpha_i = \frac{1}{3}, \frac{1}{2}, \; i = 1, ..., I \tag{2.2.1}$$

where Y_{it} is output of country i, at time t, A_t is common stock of ideas, K_{it} is the capital stock, and H_{Yit} is the quantity of human capital.

The first element in the production function is new capital, which is produced via the capital-accumulation process, given by

$$\dot{K}_{it} = s_{Kit} Y_{it} - d_i K_{it}, \qquad K_{i0} > 0 \tag{2.2.2}$$

where s_{Kit} is investment rate and $0 < d_i < 1$ is the depreciation rate.

The second element is aggregate human capital, which is described as

$$H_{Yit} = h_{it} L_{Yit} \tag{2.2.3}$$

$$h_{it} = e^{\psi_i \ell_{hit}}, \quad \psi_i > 0 \tag{2.2.4}$$

where h_{it} is human capital per person, L_{Yit} the total amount of labour employed in producing the output, and ℓ_{hit} is the amount of time an individual spends in accumulating human capital. There is also a resource constraint on labour in each economy. After excluding the time spent in school, the endowed time of each individual is divided between producing goods and producing ideas. So, the resource constraint is as follows:

$$L_{Ait} + L_{Yit} = L_{it} = (1 - \ell_{hit}) N_t, \tag{2.2.5}$$

$$N_t = N_0 e^{nt}, \qquad N_0 > 0,\ n > 0, \tag{2.2.6}$$

where L_{it} denotes employment, N_t denotes the number of agents in each economy at time t, which grows at constant exogenous rate $n > 0$.

Now, I can rewrite the production function expressed in (2.2.1) in terms of output per worker as follows:

$$y_{it} = \left(\frac{K_{it}}{Y_{it}}\right)^{\frac{\alpha_i}{1-\alpha_i}} \ell_{Yit} h_{it} A_t^{\frac{\sigma_i}{1-\alpha_i}}, \quad \ell_{Yit} \equiv L_{Yit}/L_{it} \tag{2.2.7}$$

where $y_{it} \equiv Y_{it}/L_{it}$, output per person, K_{it}/Y_{it}, is the capital-output ratio, and ℓ_{Yit}

is the fraction of the labour force that produces the output. Taking the natural logarithm of (2.2.7) gives the following:

$$ln(TFP_{it}) = ln(y_{it}) - \frac{\alpha_i}{1-\alpha_i} ln\left(\frac{K_{it}}{Y_{it}}\right) - ln(\ell_{Yit}) - ln(h_{it}) = \frac{\sigma_i}{1-\alpha_i} ln(A_t), \quad (2.2.8)$$

where $\frac{\sigma_i}{1-\alpha_i} A_t$ captures total factor productivity (TFP_{it}), which varies across countries and over time.[2] I include the number of hours worked per year as a measure of labour input, which controls for the differences in the number of hours worked in each country.

2.3 Measuring stock of knowledge: technical versus managerial ideas

In this paper, the measure of new ideas is obtained from The SCImago Journal and Country Rank which includes both the journals and the country scientific indicators developed from the information contained in the Scopus® database (Elsevier B.V.). The journals are grouped by subject and country. I extract the number of citable documents published for the selected year, by country of publication, in each subject area (only articles, reviews, and conference papers are considered). This data includes 27 subject areas. Using this information, I construct two measures of new ideas, namely the technical and managerial flow of new ideas. Technical ideas cover 21 subject areas, including multidisciplinary, agricultural and biological sciences, biochemistry, genetics and molecular biology, chemical engineering, chemistry, computer

[2] See Hasanzadeh and Khan. (2017).

science, earth and planetary sciences, energy, engineering, environmental science, immunology and microbiology, materials science, mathematics, medicine, neuroscience, nursing, pharmacology, toxicology and pharmaceutics, physics and astronomy, veterinary, dentistry, and the health professions. Managerial ideas are categorized into three main subject areas: business-management-accounting, economics-econometrics-finance, and decision sciences.

To construct the measure of the stock of technical and managerial ideas for each country, I use a standard perpetual inventory method. The stock of ideas (${S^j}_{it}$) in country i, in year t, is as follows:

$$
\begin{aligned}
{S^j}_{i,t} = {S^j}_{i,t-1}(1-\delta) + {f^j}_{i,t} \ \ , \ t = 1997, ..., 2014, \\
{S^j}_{i,1996} = {f^j}_{i,1996}/(\delta + {g_f}^j),
\end{aligned}
\tag{2.3.1}
$$

where the superscript j represents the technical, managerial, and patent variables; ${f^j}_{i,t}$ is the number of new citable documents, and ${g_f}^j$ is the average growth rate of new citable documents between 1996 and 2014, in country i. The depreciation rate, δ, is set to 0.15, which is similar to that in the patent literature.

2.4 Model specification

The general framework for analysing the dynamic panel, in this paper, is a model that is based on the pooled mean group estimator (PMG) developed by Pesaran et al. (1999). The PMG presents the autoregressive distributed lag (ARDL) model in error-correction form. One of the main features of the ARDL model is that it can be used even with variables with different orders of integration. In other words, the ARDL model allows us to incorporate I(0) and I(1) variables in the same estimation. Having non-stationary variables in our model increase the risk of having spurious results.[3] Due to the presence of cointegration among the variables used in this study, I use PMG model to estimate a long-run relationship in a panel framework. The selected PMG estimator model is augmented with lags of both the dependent and independent variables which simultaneously correct for the problem of residual serial correlation and endogenous regressors.

Pesaran et al. (1999) propose estimating the error-correction model using the following autoregressive distributed lag, ARDL (p_i,q_i) model:

$$\begin{aligned} \Delta\ lnTFP_{i,t} &= \textstyle\sum_{j=1}^{p-1} \gamma_j^i \Delta\ lnTFP_{i,t-j} + \sum_{j=0}^{q-1} \delta_j^i \Delta\ lnX_{i,t-j} \\ &+\varphi_i[lnTFP_{i,t-1} - ({\beta^i}_0 + {\beta^i}_1 lnX_{i,t-1})] + u_{it}, \end{aligned} \tag{2.4.1}$$

where p_i is the lag of dependent variable and q_i is the lag of independent variables. $lnTFP_{i,t}$ is the natural log of total factor productivity calculated using (2.2.8) and X is a set of independent variables. Parameter γ and δ represent the short-run coefficient of the lagged dependent and independent variables respectively. Parameter β represents the long-run coefficients, and φ is the coefficient of the speed of adjustment to long-run

[3] I test for the presence of unit roots to ensure that no series exceeds I(1) order of integration. I use the tests of Im et al. (2003), Breitung (2000), Levin et al. (2002) and Hadri (2000). The results of these tests are available upon request.

equilibrium. The term in square bracket of (2.4.2) describes the long-run regression using the following equation:

$$ln\,TFP_{i,t} = \beta_0^i + \beta_1^i\, lnX_{i,t} + \epsilon_{it} \quad where\ \epsilon_{it} \sim I(0). \tag{2.4.2}$$

Equation (2.4.2) can be estimated using three different estimators: the mean group (MG) model, the pooled mean group (PMG), and the dynamic fixed effects (DFE) estimator. Among the three different estimators in the dynamic panel framework, I use the pooled mean group (PMG) estimator, which provides a useful intermediate alternative between estimating the separate country regressions (the MG case) and the fixed-effects estimator, which imposes homogeneity on all of the slope coefficients and error variances across countries. The PMG allows for short-run heterogeneous dynamics, but it also imposes a long-run homogeneous relationship for the countries in the sample. Given that the categorized countries have access to common technologies, it is reasonable to believe in the existence of common long-run coefficients across each group of countries. Since I categorize the countries in the study according to similarities in their measures of income level and level of liberal-democracy, I expect the long-run equilibrium relationship between the variables to be similar across the countries in each category. The short-run adjustment is allowed to be country-specific because the spillover of ideas has widely different impacts, depending on the country. The PMG allows the speed of adjustment to differ across countries. The assumption of the same speed of convergence across countries is consistent with the neoclassical model only if both the rates of technological and population growth are the same across countries (Bassanini and Scarpetta (2002)). Pesaran et al. (1999) demonstrate that the PMG's allowance for short-run parameter heterogeneity yields more reliable estimates of the long-run responses, and can also affect the estimated speeds of convergence toward long-run equilibrium.[4] Taking the maximum lag as being equal to one, the ARDL (1,1,0) equation is given by the following:

$$\begin{aligned}\Delta\ lnTFP_{i,t} &= \varphi_i(lnTFP_{i,t-1} - \beta_1 lnS^j{}_{i,t-1} - \beta_2 lnS^j{}_{-i,t-1} - \beta_3 ER_{i,t}) \\ &\quad +\gamma_1\Delta\ lnS^j{}_{i,t} + \gamma_2\Delta\ lnS^j{}_{-i,t} + \gamma_3\Delta ER_{i,t} + u_{it},\end{aligned} \quad (2.4.3)$$

where $lnTFP_{i,t}$ is the natural log of total factor productivity calculated using (2.2.8), $S^j_{i,t-1}$ is the stock of knowledge at the beginning of time t, at country i, and $S^j_{-i,t-1}$ is the stock of knowledge in the rest of the world. The control variable $ER_{i,t}$ captures the business-cycle effect and is equal to one minus the unemployment rate.[5] γ represent the short-run coefficient of the lagged independent variables, β represents the long-run coefficients, and φ is the coefficient of the speed of adjustment to long-run equilibrium.

[4]I used Hausman test to choose among MG, PMG, and DEF estimators. The results show PMG estimation method is more suitable.

[5]The models are also estimated using year dummies to control for business-cycle effect. However, just estimated models without year dummies which provide better results are presented here. See Table 2.9.

2.5 Empirical analysis

2.5.1 Data description

This study adopts a panel-data approach and covers 60 countries for the period 1996 to 2014. The countries are classified based on two different measures. The first measure is obtained from the World Bank's classification of economies, which is based on the level of gross national income and includes low-, lower-middle-, upper-middle- and high-income countries. Table 2.1 provides a list of the countries in the sample and includes 39 high-, 13 upper-, and 8 lower-middle-income countries. In the estimations that are based on the countries' levels of income, I consider upper- and lower-middle-income countries together as the middle-income group of countries. The second classification is based on political and civil rights and is taken from the annual report of Freedom House, which tracks the degree of liberal-democracy in countries around the world. Table 2.2 shows 44, 12, and 4 countries that are the most-liberal, partially liberal, and least-liberal countries, respectively. The combined Gastil index of liberal-democracy (Freedom House) adds together the Gastil indexes of civil liberties and political rights. Each component gives a score of 1 for the most-liberal-democratic regimes, to 7 for the least, so that 2 is the best score and 14 is the worst. This method of classification is based on an average of the combined index for each country over the period 1996 to 2014.

Two groups of data are used. The first group is related to the calculation of TFP. Here, the data are drawn from PWT 9.0, and includes real GDP at constant national prices (in mil, 2011 US$); the capital stock at constant national prices (in millions of 2011 US$); the index of human capital per person, based on the number of years of schooling and returns to education; the number of persons actively engaged in the labour force (in millions) and the population in millions; and the average annual number of hours worked by persons engaged in the labour force. The number of researchers working in the R&D sector was obtained from the World Bank publication, World Development Indicators. For countries with missing data on the number of researchers, I use average growth rate for filling missing values.

The second group of data is related to the calculation of the stock of ideas. Two proxies are used to measure the level of innovative activity in each economy: patents and scientific publications. The annual number of U.S. patents filed by residents of a country is one of the most basic measures of the level of innovative activity that bears commercial value and that is taking place within an economy. Since different patenting agencies have different criteria for the novelty of an original innovation, I consider only patents granted by the UPSTO. By using only U.S. patent data, I have a consistent set of minimum standards for an innovation (Chen and Dahlman (2004)). The second proxy is defined, using scientific publications collected from SCImago. (2007). As is explained in section 2.3, I divide the number of citable documents published in each country into two groups: technical ideas and managerial ideas. The employment rate is included, in the model, as a control variable to account for the impact of the business cycle.

2.5.2 Results

In this part, I provide the examination results of knowledge spillovers on TFP based on two different country classification applied in this study. The first classification follows the World Bank's classification of economies, according to the country's level of gross national income, which includes low-, lower-middle-, upper-middle-, and high-income countries. The second classification is for the level of liberal-democracy, a classification that uses the Gastil index.

Level of income classification

Table 2.3 shows the long- and short-run parameters for four PMG regressions in high-income countries. The first three columns show the estimation results, using citable documents as a measure of the stock of knowledge. The last column shows the estimation results, using the stock of patents. The long-run coefficient of the domestic stock of knowledge in all the PMG regressions appears to be positive and highly significant. The estimated results also indicate a negative and significant impact of the total domestic stock of ideas on TFP in the short run. In the long run, all of the regressions show that the international stock of knowledge suggests a negative and significant effect on the total factor productivity of high-income countries. In terms of their magnitude, managerial ideas and patents have the most and least effect, respectively, on long-run growth in TFP in high-income countries. Furthermore, the elasticity of TFP, with respect to the intranational stock of managerial ideas, is around three times larger than it is for technical ideas. The speed of convergence toward long-run equilibrium is higher in the estimated model that uses patents as the metric. Next, I examine to what extent the above findings vary by income level, by re-estimating the models for the middle-income countries (including, lower-middle- and upper-middle- income countries). Table 2.4 shows the results of this estimation. This time, the long-run coefficient of the internal stock of ideas, using all ideas and technical ideas, appears to be positive and highly significant. However, in the long run, the internal stock of managerial ideas shows a negative and insignificant effect on the TFP of middle-income countries. The internal stock of patents denotes a negative and statistically significant effect on productivity, in the long run. With regards to all four regressions, the internal stock of ideas, in both forms (citable documents and patents) does not show any significant effects in the short run. In the long run, however, the elasticity of TFP, with respect to the rest of the world's stock of knowledge, is positive and highly significant in all four estimated models. However, in the short run, both the external stock of managerial ideas and patents do not show any significant effects on the middle-income countries' TFP.

To summarize, these results reinforce the notion that the home country's level of income matters in knowledge dissemination. If the home country belongs to the middle-income group, then the domestic stock of managerial ideas does not have any significant effect on long-run growth in TFP. However, if the home country is categorized as a high-income country, then the stock of all forms of ideas, even managerial ones, will contribute to a higher level of long-run growth in TFP. In terms of magnitude, the managerial stock of knowledge shows the greatest intranational and international long-run spillovers in the TFP of high-income countries. In regressions that use all ideas and technical ideas, middle-income countries show a higher speed of convergence. However, in high-income countries, the speed at which the model returns to equilibrium after a shock is higher in regression models that use managerial ideas and patents.

Liberal-democracy classification

A country's level of liberal-democracy also has an effect on how knowledge spillovers impact TFP. Here, the Gastil index of liberal-democracy (Freedom House) classification is used as the metric. Tables 2.5 and 2.6 show the estimates obtained from the most liberal-democratic countries (Gastil index of liberal-democracy <5) and partially liberal-democratic countries (Gastil index of liberal-democracy of between $5 \leq$ and ≤ 10). Taking into account the whole set of regression results, it can be concluded that, in the long run, intranational knowledge spillovers have always positively contributed to the TFP of the most liberal-democratic countries. However, the results for the countries with partially liberal-democratic regimes show that the internal stock of managerial knowledge has a depressing effect on TFP in the long run. In the long run, the domestic stock of patents implies a large magnitude of knowledge spillover in the most liberal-democratic countries. But, in countries with only partial democracy, the stock of all citable documents has the greatest effect on TFP in the long run. In contrast to countries with the most liberal -democratic regimes, the international stock of managerial knowledge stimulates the productivity of those countries with partially liberal-democratic regimes. In terms of the speed with which the long-run effect is realized, all of the estimated models on the partially liberal-democratic countries show higher speeds of convergence, compared to the ones of the most liberal-democratic countries. In my sample, all of the partially liberal-democratic countries are among the middle-income ones, except for Singapore.

Table 2.7 shows the results for the least liberal-democratic countries. Here, the only variable that has a stimulating effect on TFP, in the long run, is the international knowledge spillover of managerial ideas. However, the results can be biased, since only four countries are classified as being in the least-liberal-democratic group.

Comparing the estimations for the high-income countries with the most-liberal-democratic ones shows larger domestic managerial knowledge spillovers.[6] It is possible that this is because not all of the most-liberal-democratic countries are in the highest income level. Tables 2.1 and 2.2 show that all high-income countries are among the most-liberal-democratic regimes, except for Singapore. Regardless of whether a country is classified as high-income or the most-liberal-democratic regime, the domestic spillovers are quite the same for both technical ideas and all ideas. For high-income countries, however, the impact of domestic spillovers of managerial ideas is almost four times that of the high-liberal-democratic countries. This can be because, in my sample of countries, there are more countries classified as the most-liberal-democratic regimes that belong to the middle-income group (Brazil, Bulgaria, Costa Rica, Jamaica and Romania). A comparison among all of the estimated models, under different country classifications, shows that domestic spillovers of managerial innovations have the highest influence on the TFP of high-income countries. Yet, the

[6] I exclude the least-democratic countries in this comparison due to the limited number of observations in this estimation.

impact of foreign (international) managerial knowledge spillovers on productivity is greatest among the partially liberal-democratic and middle-income countries. If we compare all of the estimated models with different country classifications (except for the least-democratic-countries classification), we notice that international managerial-knowledge spillovers have larger impact on TFP in the countries that are categorized as middle-income or partially liberal-democratic.

2.6 Estimating ideas production function

In this section, I estimate the sensitivity of ideas production to the human capital resources that are devoted to the ideas-producing sector and the pre-existing stock of knowledge. Consider the national-ideas production function for country i,

$$f_{i,t} = \delta L^{\lambda}{}_{Ai,t} \; S^{\phi}{}_{w,t-1} \tag{2.6.1}$$

where $f_{i,t}$ is the flow of new ideas in country i, at time t. These new ideas are in the form of technical, managerial, or all ideas that are found in citable documents. $L_{Ai,t}$ shows the number of researchers in R&D sector, and $S_{w,t-1}$ is the world's stock of ideas at the beginning of the current period. Since this stock of ideas is in the form of citable documents that are immediately available to be used by all economies, I consider the effect of the whole stock of ideas on a certain country's discovering new ideas. In the case of measuring new ideas by patent, I apply the assumption of Porter and Stern (2000), which is that the ideas production in a given year will be reflected in the patents that are granted three years in the future. I define the national-ideas-production function for country i as follows:

$$PATS_{i,t} = \delta L^{\lambda}{}_{Ai,t-3}\ S^{\phi}{}_{i,t-3}, \tag{2.6.2}$$

where $PATS_{i,t}$ is the number of patents granted to country i. Table 2.8 presents the results of the regression of the flow of new ideas on the amount of labour employed in the ideas-producing sector, and the measure of the stock of knowledge and controls, for the time period under review.

The estimated sensitivity to an increase in the stock of all ideas ($\hat{\phi}$) is 1.449, while the return to the research effort ($\hat{\lambda}$) is 0.352. By separating the measurement of new ideas, I find a higher sensitivity to the stock of managerial innovations ($\hat{\phi}$=2.788), compared to the technical ones ($\hat{\phi}$=1.355). The results also show that increasing the number of researchers does not affect the research productivity that results from managerial ideas.

2.7 Conclusions

This paper uses a new data set on scientific publications, by different subject areas, to examine the effect of knowledge spillovers on productivity growth at the country level for the period 1996 to 2014. I apply the pooled mean group estimator to deal with heterogeneity problems. I consider both domestic and international knowledge spillovers to investigate the effects of each of these knowledge spillovers on the total factor productivity of the destination country. The results do not confirm the higher international spillovers of scientific publications compare to patents. Comparing all the estimations highlights the important role domestic knowledge spillovers play in high-income and highly liberal-democratic countries. In contrast, the results show the significant role international spillovers play in fostering the productivity growth of middle-income countries and countries with partially liberal-democratic regimes. Regardless of which metric is utilized, international knowledge spillovers have always contributed to higher productivity in middle-income counties. Yet, in the long run, foreign spillovers have a negative impact on the productivity of high-income countries. By distinguishing between managerial and technical ideas, I find evidence that managerial ideas have the largest domestic spillovers in high-income countries and no effect in middle-income countries. However, international managerial knowledge spillovers have the greatest impact on the productivity of middle-income countries and countries with partially liberal-democratic regimes. The results show that managerial innovations do better in regimes where there is less democracy. One possibility would be international corporations in these countries foster international diffusion of technical and managerial knowledge. Further research should shed more light on this, including the impact on high-income countries with less liberal-democratic regimes and controlling for the effect of multinational companies on TFP, to investigate whether authoritarianism works better in terms of influencing managerial innovations or multinational companies are the main reason for higher international diffusion of knowledge in these countries.

References

Abdih, Y. and Joutz, F.: 2006, Relating the knowledge production function to total factor productivity: An endogenous growth puzzle, *IMF Staff Papers* **53**(2), 2.

Adams, J.: 1990, Fundamental stocks of knowledge and productivity growth, *Journal of Political Economy* **98**(4), 673–702.

Alexopoulos, M. and Cohen, J.: 2009, Measuring our ignorance, one book at a time: New indicators of technological change, 1909-1949, *Journal of Monetary Economics* **56**(4), 450–470.

Alexopoulos, M. and Tombe, T.: 2012, Management matters, *Journal of Monetary Economics* **59**(3), 269–285.

Bassanini, A. and Scarpetta, S.: 2002, Does human capital matter for growth in OECD countries? a pooled mean-group approach, *Economics Letters* **74**(3), 399 – 405.

Breitung, J.: 2000, *Nonstationary Panels, Panel Cointegration, and Dynamic Panels*, Vol. 15, Amsterdam: JAY Press, advances in econometrics The local power of some unit root tests for panel data, pp. 161–178.

Chen, D. H. C. and Dahlman, C. J.: 2004, Knowledge and development: a cross-section approach, *Policy Research Working Paper Series 3366*, The World Bank.

Griffith, R., Redding, S. and Reenen, J. V.: 2004, Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries, *The Review of Economics and Statistics* **86**(4), 883–895.

Guellec, D. and de la Potterie, B. V. P.: 2004, From R&D to productivity growth: Do the institutional settings and the source of funds of R&D matter?, *Oxford Bulletin of Economics and Statistics* **66**(3), 353–378.

Hadri, K.: 2000, Testing for stationarity in heterogeneous panel data, *Econometrics Journal* **3**(2), 148–161.

Hasanzadeh, S. and Khan., H.: 2017, Sources of Canadian economic growth, *Working Paper Series CEP 16-02*, Carleton University.

Im, K. S., Pesaran, M. H. and Shin, Y.: 2003, Testing for unit roots in heterogeneous panels, *Journal of Econometrics* **115**(1), 53–74.

Jones, C. I.: 1995, R&D-based models of economic growth, *Journal of Political Economy* **103**(4), 759–784.

Jones, C. I.: 2002, Sources of U.S. economic growth in a world of ideas, *American Economic Review* **92**(1), 220–239.

Lach, S.: 1995, Patents and productivity growth at the industry level: A first look, *Economics Letters* **49**(1), 101–108.

Levin, A., Lin, C.-F. and Chu, C.-S. J.: 2002, Unit root tests in panel data: asymptotic and finite-sample properties, *Journal of Econometrics* **108**(1), 1–24.

İmrohoroğlu, A. and Üngör, M.: 2016, Total factor productivity levels: Some anomalies in Penn World Tables, *Working paper* .

Pesaran, M. H., Shin, Y. and Smith, R.: 1999, Pooled mean group estimation of dynamic heterogeneous panels, *Journal of the American Statistical Association* **94**, 621–634.

Pessoa, A.: 2005, "ideas" driven growth: the oecd evidence, *Portuguese Economic Journal* **4**(1), 46–67.

Porter, M. E. and Stern, S.: 2000, Measuring the ideas production function: Evidence from international patent output, *Working Paper 7891*, National Bureau of Economic Research.

SCImago.: 2007, SJR — SCImago Journal & Country Rank. Retrieved July 21, 2015, from http://www.scimagojr.com.

Table 2.1: Income-level classification

High income	Upper middle income	Lower middle income
Australia	Argentina	Bangladesh
Austria	Brazil	Cambodia
Barbados	Bulgaria	India
Belgium	Colombia	Indonesia
Canada	Costa Rica	Pakistan
Chile	Ecuador	Philippines
Cyprus	Jamaica	Sri Lanka
Czech Republic	Malaysia	Vietnam
Denmark	Peru	
Estonia	Romania	
Finland	Russian Federation	
France	Thailand	
Germany	Turkey	
Greece		
Hungary		
Iceland		
Ireland		
Italy		
Japan		
Latvia		
Lithuania		
Luxembourg		
Malta		
Netherlands		
New Zealand		
Norway		
Poland		
Portugal		
Singapore		
Slovakia		
Slovenia		
South Korea		
Spain		
Sweden		
Switzerland		
Trinidad & Tobago		
United Kingdom		
United States		
Uruguay		

Table 2.2: Liberal-democracy classification

The most-liberal	Partial-liberal	The least-liberal
Argentina	Bangladesh	Vietnam
Australia	Colombia	Russian Federation
Austria	Ecuador	Cambodia
Barbados	India	Pakistan
Belgium	Indonesia	
Brazil	Malaysia	
Bulgaria	Peru	
Canada	Philippines	
Chile	**Singapore**	
Costa Rica	Sri Lanka	
Cyprus	Thailand	
Czech Republic	Turkey	
Denmark		
Estonia		
Finland		
France		
Germany		
Greece		
Hungary		
Iceland		
Ireland		
Italy		
Jamaica		
Japan		
Latvia		
Lithuania		
Luxembourg		
Malta		
Netherlands		
New Zealand		
Norway		
Poland		
Portugal		
Romania		
Slovakia		
Slovenia		
South Korea		
Spain		
Sweden		
Switzerland		
Trinidad and Tobago		
United Kingdom		
United States		
Uruguay		

Table 2.3: High-income countries

	Dependent Variable: $log(A_t)$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Internal citable documents stock)$_{t-1}$	0.073***	0.074***	0.201***	
	(0.028)	(0.027)	(0.027)	
ln(Rest of world citable documents stock)$_{t-1}$	−0.223***	−0.232***	−0.298***	
	(0.043)	(0.043)	(0.036)	
ln(1+Internal patent stock)$_{t-1}$				0.067***
				(0.019)
ln(1+Rest of world patent stock)$_{t-1}$				−0.039*
				(0.023)
Employment rate$_t$	−0.235***	−2.483***	−0.214	0.039
	(0.393)	(0.389)	(0.221)	(0.170)
Error-correction coefficient	−0.190***	−0.187***	−0.191***	−0.211***
	(0.028)	(0.028)	(0.035)	(0.036)
Δln(Internal citable documents stock)	−0.465***	−0.462***	−0.027	
	(0.168)	(0.169)	(0.046)	
Δln(Rest of world citable documents stock)	1.312***	1.325***	0.278**	
	(0.294)	(0.295)	(0.124)	
Δln(Internal patent stock)				−0.050
				(0.052)
Δln(Rest of world patent stock)				−0.029
				(0.096)
ΔEmployment rate	1.288**	1.288***	1.167***	1.115***
	(0.196)	(0.195)	(0.220)	(0.191)
Intercept	1.267***	1.297***	0.808***	0.386***
	(0.191)	(0.197)	(0.154)	(0.067)
No. of Countries	39	39	39	39
No. of Observations	702	702	702	702

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.4: Middle-income countries

	Dependent Variable: $log(A_t)$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Internal citable documents stock)$_{t-1}$	0.074***	0.074***	-0.006	
	(0.023)	(0.023)	(0.032)	
ln(Rest of world citable documents stock)$_{t-1}$	0.178***	0.174***	0.495***	
	(0.063)	(0.065)	(0.068)	
ln(1+Internal patent stock)$_{t-1}$				-0.302^{***}
				(0.039)
ln(1+Rest of world patent stock)$_{t-1}$				1.246***
				(0.110)
Employment rate$_t$	3.518***	3.399***	-6.960^{**}	0.271
	(0.063)	(0.625)	(2.750)	(0.811)
Error-correction coefficient	-0.246^{***}	-0.247^{***}	-0.113^{**}	-0.161^{***}
	(0.072)	(0.071)	(0.046)	(0.052)
Δln(Internal citable documents stock)	-0.102	-0.091	-0.002	
	(0.210)	(0.212)	(0.028)	
Δln(Rest of world citable documents stock)	2.085***	2.147***	0.261	
	(0.481)	(0.481)	(0.190)	
Δln(Internal patent stock)				-0.096
				(0.067)
Δln(Rest of world patent stock)				-0.270
				(0.188)
Δ Employment rate	1.466**	1.458**	3.176***	1.754***
	(0.653)	(0.644)	(1.150)	(0.459)
Intercept	-1.727^{***}	-1.693^{***}	0.019	-2.501^{***}
	(0.511)	(0.495)	(0.023)	(0.832)
No. of Countries	21	21	21	20
No. of Observations	378	378	378	360

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.5: Most-liberal democratic countries

	Dependent Variable: $log(A_t)$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Internal citable documents stock)$_{t-1}$	0.072^{**}	0.077^{***}	0.041^{***}	
	(0.030)	(0.029)	(0.012)	
ln(Rest of world citable documents stock)$_{t-1}$	-0.224^{***}	-0.241^{***}	-0.113^{***}	
	(0.046)	(0.046)	(0.024)	
ln(1+Internal patent stock)$_{t-1}$				0.098^{***}
				(0.018)
ln(1+Rest of world patent stock)$_{t-1}$				-0.066^{***}
				(0.022)
Employment rate$_t$	-2.368^{***}	-2.627^{***}	-0.168^{*}	0.102
	(0.396)	(0.398)	(0.089)	(0.174)
Error-correction coefficient	-0.172^{***}	-0.166^{***}	-0.170^{***}	-0.194^{***}
	(0.020)	(0.020)	(0.027)	(0.032)
Δln(Internal citable documents stock)	-0.447^{***}	-0.443^{***}	−0.026	
	(0.154)	(0.154)	(0.035)	
Δln(Rest of world citable documents stock)	1.337^{***}	1.361^{***}	0.245^{**}	
	(0.254)	(0.255)	(0.106)	
Δln(Internal patent stock)				−0.041
				(0.047)
Δln(Rest of world patent stock)				−0.055
				(0.097)
ΔEmployment rate	1.169^{***}	1.170^{***}	1.039^{***}	0.984^{***}
	(0.141)	(0.141)	(0.145)	(0.142)
Intercept	1.118^{***}	1.158^{***}	0.474^{***}	0.350^{***}
	(0.137)	(0.143)	(0.082)	(0.060)
No. of Countries	44	44	44	44
No. of Observations	792	792	790	792

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.6: Partial-liberal democratic countries

	Dependent Variable: $log(A_t)$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Internal citable documents stock)$_{t-1}$	0.323***	0.314***	-0.106^{***}	
	(0.039)	(0.038)	(0.019)	
ln(Rest of world citable documents stock)$_{t-1}$	-0.691^{***}	-0.689^{***}	0.325***	
	(0.092)	(0.091)	(0.049)	
ln(1+Internal patent stock)$_{t-1}$				0.056**
				(0.022)
ln(1+Rest of world patent stock)$_{t-1}$				-0.110^{**}
				(0.043)
Employment rate$_t$	3.125***	2.911***	2.780***	3.197***
	(0.606)	(0.588)	(0.341)	(0.176)
Error-correction coefficient	-0.347^{***}	-0.348^{***}	-0.336^{**}	-0.329^{***}
	(0.133)	(0.132)	(0.108)	(0.115)
Δln(Internal citable documents stock)	0.232	0.243	0.237	
	(0.147)	(0.155)	(0.158)	
Δln(Rest of world citable documents stock)	2.936***	2.979***	0.712*	
	(0.910)	(0.922)	(0.428)	(0.368)
Δln(Internal patent stock)				-0.066
				(0.055)
Δln(Rest of world patent stock)				-0.699^{*}
				()
ΔEmployment rate	1.433*	1.443*	2.025**	2.087**
	(0.857)	(0.841)	(0.880)	(0.836)
Intercept	1.903**	2.001**	-1.808^{***}	-0.192
	(0.768)	(0.798)	(0.561)	(0.117)
No. of Countries	12	12	12	12
No. of Observations	216	216	216	216

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.7: Least-liberal democratic countries

	Dependent Variable: $log(A_t)$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Internal citable documents stock)$_{t-1}$	0.044	0.045	0.015	0.118
	(0.035)	(0.036)	(0.054)	
ln(Rest of world citable documents stock)$_{t-1}$	0.237	0.223	0.507***	
	(0.161)	(0.169)	(0.119)	
ln(1+Internal patent stock)$_{t-1}$				0.118
				(0.132)
ln(1+Rest of world patent stock)$_{t-1}$				−0.015
				(0.344)
Employment rate$_t$	7.352***	7.472***	−10.603*	0.160
	(1.289)	(1.326)	(5.974)	(1.612)
Error-correction coefficient	−0.330***	−0.326**	−0.247	−0.256***
	(0.131)	(0.130)	(0.184)	(0.182)
Δln(Internal citable documents stock)	−0.830*	−0.843*	0.043	
	(0.496)	(0.499)	(0.081)	
Δln(Rest of world citable documents stock)	2.207	2.228	0.029	
	(1.603)	(1.598)	(0.450)	
Δln(Internal patent stock)				−0.352
				(0.402)
Δln(Rest of world patent stock)				0.302
				(0.351)
ΔEmployment rate	2.142	2.105	8.171	1.470
	(2.564)	(2.504)	(6.182)	(1.394)
Intercept	−3.748**	−3.671**	0.856***	0.108
	(1.563)	(1.542)	(0.603)	(0.099)
No. of Countries	4	4	4	3
No. of Observations	72	72	68	54

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.8: TFP and the Stock of Ideas

	Dependent Variable: $log(P_{i,t})$			
	All Ideas	Technical Ideas	Managerial Ideas	Patent
ln(Existing Stock of Ideas)	1.449***	1.355***	2.788***	0.455***
	(0.464)	(0.469)	(0.545)	(0.068)
ln(Number of Researchers)	0.352**	0.353**	0.248	0.251***
	(0.138)	(0.137)	(0.175)	(0.100)
Constant	Yes	Yes	Yes	Yes
Trend	Yes	Yes	Yes	Yes
No. of Countries	60	60	60	59
No. of Obs	1080	1080	1067	944

Notes: ** and *** indicate significance at 5% and 1%. All ideas include technical plus managerial ideas.

Table 2.9: Total stock of ideas in high-income countries

	Dependent Variable: $log(A_t)$		
	MG	PMG	DFE
ln(Internal citable documents stock)$_{t-1}$	0.074	0.074	-0.169^{*}
	(0.303)	(0.171)	(0.098)
ln(Rest of world citable documents stock)$_{t-1}$	-0.971^{*}	-1.327^{***}	-2.275^{***}
	(0.533)	(0.087)	(0.795)
Employment rate$_t$	0.117	0.390^{***}	-1.287^{**}
	(0.371)	(0.122)	(0.588)
Error-correction coefficient	-0.874^{***}	-0.475^{***}	-0.085^{***}
	(0.061)	(0.044)	(0.016)
Δln(Internal citable documents stock)	0.144	0.089	-0.122^{*}
	(0.192)	(0.173)	(0.067)
Δln(Rest of world citable documents stock)	0.653^{*}	0.850^{***}	0.452^{**}
	(0.350)	(0.307)	(0.215)
ΔEmployment rate	0.901^{***}	0.986^{***}	0.923^{***}
	(0.193)	(0.165)	(0.145)
Intercept	-37.356^{**}	-54.752^{***}	-15.635^{***}
	(18.252)	(5.624)	(5.660)
No. of Countries	39	39	39
No. of Observations	702	702	702
Year Dummies	Yes	Yes	Yes

Notes: *, ** and *** indicate significance at 10%, 5% and 1%. All ideas include technical plus managerial ideas.

Chapter 3

Interest Rates and Capacity Utilization: An Empirical Assessment

3.1 Introduction

The importance of including the topic of capacity utilization in discussions on monetary policy has long been recognized. Policymakers and economic agents consider changes in capacity utilization as a signal of future changes in the economic environment. Capacity utilization is one of several factors that determine why the effectiveness of monetary policy could vary over a business cycle. Capacity utilization features prominently in descriptions of monetary policy's transmission mechanism for at least two reasons. First, it factors in the conventional view of how monetary policy affects the economy. In this case, monetary policy transmission happens through the conventional interest rate/cost –of-capital channel.[1] Changes in the cost of borrowing lead businesses to adjust their investment and spending and, as a result, either their capital stock or their capital-utilization rate. Changing the utilization or the quantities of the different factors employed implies different adjustment costs. These different adjustment costs have different implications for profits and, consequently, for manufacturing output and capacity utilization. In the short term, movements in the capacity-utilization rate primarily reflect changes in manufacturing-industry output. In the long run, however, the growth rate of capacity utilization (of industries) changes in response to changes in business investment and technological progress (Garner (1994)). Second, even when monetary policy is constrained by a zero lower bound (as at present in the U.S., Japan, and many other countries) and unconventional channels, such as large-scale asset purchases and forward guidance are proceeding to affect long-term interest rates, capacity utilization continues to play an important role in how these unconventional monetary policies are viewed as affecting the economy. Wu and Xia (2016) argue that following the Great Recession, the Fed has used unconventional policy measure to successfully lower the shadow rate, which has led to increases in industrial production and capacity utilization and, consequently, decreases in the unemployment rate.

There is a large literature that explores the macroeconomic effect of business cycle-fluctuations on capacity utilization, mostly using a dynamic stochastic general equilibrium (DSGE) model.[2] There are also many studies that investigate the rela-

[1] For example see. García-Schmidt and Woodford (2016).

[2] For example, see Greenwood et al. (1988), Boileau and Normandin (2003), Krüger (2008), and Wu and Xia (2016).

tionship between capacity utilization and inflation, using Phillips curve.[3] However, much less empirical work has been done based on microeconomic evidence and there is little evidence that establishes the empirical relationship between interest rates and capacity utilization. The principal goal of this paper is to fill this gap by providing a framework for understanding the link between these two factors.

The capacity-utilization rate is quite different across industries. This cross-industry heterogeneity can be due to individual industry characteristics, such as the sensitivity of the capital intensity of production or the degree of openness which captures exchange rate fluctuations. Individual industry characteristics also play an important role in the transmission of monetary policy. For example Alvarez-Lois (2005) has argued that these differences are related to production inflexibilities and idiosyncratic demand uncertainties. Production inflexibilities mean firms cannot immediately modify their production possibilities in response to changes in the business environment. For instance, many firms cannot adjust their capacity to produce more goods, in the short-run, in response to an increase in excess demand. There are also cases wherein the existence of uncertainty at the time firms are making their capacity choices leads them to underutilize equipment. Low capacity-utilization rates suggests that firms have idle or excess capacity. The idle capacity reflects the shortage demand in manufactured goods. In this case firms try to cut their costs and do not invest any more in plant and equipment so as to expand production. As Figure 3.1 shows, after the 2008 crisis, slack in production was the highest and capacity utilization the lowest

[3] See, for example, Garner (1994), Finn (1996), Emery and Chang (1997), Belton and Cebula (2000), and Dotsey and Stark (2005).

in nonmetallic minerals, wood, textiles, and printing, according to Federal Reserve data. This raises the questions as to which U.S. manufacturing industry policy makers should be most anxious about.

Most previous studies on capacity utilization have concentrated on the manufacturing sector as a whole without providing a more disaggregated view of the problem.[4] This paper provides quantitative results on the connection between interest rates and capacity utilization at the industry-level. There are two reasons for exploring this disaggregated analysis: First, each of these industries behaves differently in response to changes in interest rates over time. Second, in theory, interest rates can have either a positive, negative, or no effect on capacity utilization. Therefore, studying the manufacturing sector at the aggregate level can obscure our understanding of how interest rates affect capacity utilization. From a policy perspective, however, it would be useful to know the capacity utilizations of the industries that are more sensitive to fluctuations in interest rates. Some studies, such as Peersman and Smets (2005), show that the durability of the product produced by the industry has a highly significant and positive effect on its sensitivity to changes in monetary policy. It is for this reason that a rise in interest rate has more impact on demand for durable goods than the demand for non-durables. The second question this paper asks is whether the capacity utilization of durable-goods industries is more sensitive to changes in interest rates. To answer this question, I conduct a disaggregated analysis of manufacturing industries.

The main objective of this paper is to contribute to the literature by analyzing

[4]See, for example, Berndt and Morrison (1981), Garofalo and Malhotra (1997) and Kim (1999).

cross-industry heterogeneity on the basis of the sensitivity of capacity utilization to changes in the interest rate. For this reason I distinguish between the direct and indirect effects of interest rates on capacity utilization. Interest rates have both a direct and an indirect effect through the cost-of-capital channel. Most of the previous literature on capacity utilization considers capital stock as an exogenously given variable; however, this approach can bias the estimated parameters. Another contribution of this paper is to correct this problem by using a sample that includes manufacturing industries with different levels of capital utilization. In contrast to the concept of capacity utilization, capital utilization may be defined as the ratio of the desired stock of capital (given the quantity of the output and the input prices) to the actual stock of capital (Berndt and Fuss (1989)). Capital utilization is different from capacity utilization. The former measures the intensity with which capital operates, and the latter measures the actual output relative to the firm or industry's potential. The capital-utilization rate affects the user's cost of capital by changing the depreciation rate and it gives the firm flexibility in responding to a shock to demand and/or cost. In this case, the level of output is determined by the firm's choice of inputs and their utilization of these inputs. Shapiro (1986) argued that firms may respond to temporary shocks by adjusting the utilization of their inputs; they can respond to permanent shocks by adjusting the stock of their inputs. Therefore capital utilization is an indirect transmission channel of monetary policy that cannot be ignored.

In this paper I identify the main factors that affect capacity utilization. I also present a framework in which elasticities of capacity utilization are measured with respect to changes in economic conditions; I do so by using the 2SLS fixed effects estimation in a panel setting for 21 U.S. manufacturing industries for the period 1975 to 2011. The main findings are as follows: (a) In most industries, a cut in the interest rate does not simultaneously stimulate their capacity utilization. Interest-rate change only have an immediate negative influence on the capacity utilization of food industries, which capture less than ten percent of total manufacturing production. (b) In contrast to previous studies, I do not find evidence regarding more sensitivity of durable-goods industries to interest-rate changes. In terms of magnitude, leather and allied products from non-durable manufacturing industries and computer and electronic products from durable manufacturing industries, respectively, show the greatest sensitivity to interest rate changes. (c) In many industries, interest rates and capacity utilization move in the same direction. This suggests that, in response to a raise in the interest rate and a consequent increase in the cost of capital, many firms increase their capacity utilization by using their current level of capital more intensively.

In conceptualizing the channels through which monetary policy affects capacity utilization, we must keep in mind that the contemporaneous elasticity is not high; also, it is quite different across industries. Policymakers need to consider that capacity utilization is more sensitive to policy in certain sectors than it is in others; therefore, they should pay more attention to these interest-rate-sensitive industries. This means that knowledge about which sectors are more responsive to federal interest-rate changes is very important and is provided by the current research.

The rest of the paper is organized as follows. Section 3.2 shows how the theory predicts how the relationship between capacity utilization and interest rates should work in principle. Section 3.3 is devoted to an empirical analysis, including a discussion of the data sources, some descriptive statistics about the data sources, an empirical specification, industry effects, and robustness checks. The final section of this study provides a brief summary and conclusions.

3.2 Theory

Assume that each manufacturing industry has a production function for gross output as follows:

$$Y_{it} = F(K_{it}u_{it}, L_{it}, E_{it}, M_{it}, T_{it}),$$

where Y_{it} denotes the level of output in manufacturing industry i, at time t. K_{it} is the capital stock and u_{it} is an index of its utilization rate. L_{it} is the services provided by labour. Variables E_{it} and M_{it} represent the inputs of energy and materials, respectively, that are used to produce Y_{it}. T_{it} represents the state of technology. In the short run, capital is generally fixed; that is, plant size and equipment cannot be increased or decreased. The capacity utilization ratio in manufacturing industry i, at time t is

$$CU_{it} = Y_{it}/Y^*_{it}, \tag{3.2.1}$$

where Y_{it} and Y^*_{it} are the actual and capacity level of output, respectively, in manufacturing industry i, at time t. Output (Y_{it}) is chosen by firms that are using the short-run profit maximization rule, which in this case, this is defined as the point at which marginal revenue is equal to short-run marginal cost ($SRMC$). Cassels (1937) defines a capacity level of output (Y^*) as the level of output where the firms' long-run average cost curve reaches a minimum. However, a firm that is experiencing constant returns will also have constant long-run average cost which is horizontal and does not have a minimum point. Klein (1960) provides an alternative measure of capacity output that also works under constant returns to scale. He defines the capacity level of output as the point where the short-run average cost curve ($SRAC$) is tangent to the long-run average cost curve ($LRAC$). This is the point at which the $SRMC$ is equal to the long-run marginal cost ($LRMC$). The capacity-utilization ratio can be less, equal to, or greater than one indicating under-utilized, fully utilized or over-utilized capacity, respectively.

The short-run variable cost function ($SRVC$) is defined as a function of labour (L), energy (E), and materials (M) as follows:[5]

$$SRVC = WL + P_E E + P_M M = f(Y, P, g(K))$$

$$g(K) = uK. \tag{3.2.2}$$

For notational convenience, the subscripts have been dropped. Y is the output level, P is a vector of input prices, and $g(K)$ is the flow of capital services, which is defined

[5] Energy and materials are the intermediate inputs, purchased from domestic industries and foreign sources, that industries consume in producing gross output.

as a function of the capital-utilization rate (u) and the capital stock (K). Previous studies have generally treated capital stock as being exogenous to the estimation of capacity utilization or the *SRVC* function; however, capital services (capital in use) is more relevant to these concepts. For instance, during slack periods, when firms operate at less than full capacity, measuring capital stock will overestimate the contribution of the capital input to the production and capacity utilization. Therefore, using the exogenous capital stock in the equations means that there will be errors in the estimations, which results in biased parameter estimates (Lovell (1968)). Capital utilization measures the speed or intensity with which a given stock of capital equipment operates. For instance, this could be referring to the capital's workweek.[6] When firms need more capital services than what they currently have, they may buy additional physical capital or they may use what they already have more intensively. Since most firms cannot adjust the level of capital stock in the short run, they try to choose the optimal utilization rate of their capital stock. Uncertainty about the future is also an important factor in firms' investment decisions. Firms respond differently based on their expectations about the permanency of shocks. Firms may respond to permanent shocks by adjusting their capital stock and they can react to temporary shocks by modifying the utilization of their capital stock (Shapiro (1986)). The are other factors such as existence of transaction costs and market imperfections which can affect on capital utilization (Durlauf and Blume (2008)). For these reasons it is important to include capital utilization in estimation of capacity utilization.

[6] This is the main difference between the proposed *SRVC* functions in Appendix B.2 and the conventional form which ignores capital utilization. In the conventional *SRVC* function, capital refers to capital stock, but in the proposed *SRVC*, $g(k)$ refers to capital services.

In the literature, many researchers use the terms "capital utilization" and "capacity utilization" interchangeably. Berndt and Fuss (1989) show, however, that these two concepts are the same under two conditions: (a) if production has constant returns to scale; and (b) if there is only one fixed input. Most studies on capacity utilization consider only the first condition and treat capital stock as a given. However, the existence of only one capital input doesn't look realistic. For these reasons, I investigate the capacity-utilization function with a sample that includes industries with different utilization rates. This provides a better specification and a better estimation of capacity utilization.

I assume that the *SRVC* has regularity conditions as follows: it is increasing and concave in input prices; it is non-increasing and convex in K; it is linearly homogeneous in input prices; and it is non-decreasing in Y.[7]

In this paper, I do a reduced-form estimation, according to the theory.[8] From the theoretical framework we know that

$$Y^* = Y^*(uK, W, P_E, P_M, P_K, T), \tag{3.2.3}$$

where uK is the current level of capital services, which in this case is equal to the optimal level of capital services, i.e. $uK = (uK)^*$. According to (3.2.3), the capacity level of output (Y^*) is the level of output at which the current capital stock is equal

[7] For example see. Morrison (1985); Kim (1999)

[8] The empirical estimation of the model requires an explicit functional form for the variable cost function. Although the previous literature suggests a plethora of functional forms, I use a quadratic functional form in Appendix B.2 to show the theoretical link between the interest rate and capacity utilization.

to the optimal long-run capital stock. From the production function, the current level of output is a function of the input prices, capital stock, capital utilization, and technology, that is,

$$Y = Y(uK, W, P_E, P_M, T).$$

Using (3.2.1), $CU = Y(uK, W, P_E, P_M, T)/Y^*(uK, W, P_E, P_M, P_K, T)$ (where CU is capacity utilization and all the other variables have been explained), the elasticities of capacity utilization with respect to the exogenous variables are as follows:

$$\frac{\partial\ lnCU}{\partial\ lnK} = \frac{\partial\ lnY}{\partial lnK} - \frac{\partial lnY^*}{\partial lnK} \gtreqless 0$$

$$\frac{\partial\ lnCU}{\partial\ lnP_K} = -\frac{\partial lnY^*}{\partial lnP_K} = -(-\frac{\partial\ lnK^*/\partial\ lnP_K}{\partial\ lnK^*/\partial lnY}) < 0 \tag{3.2.4}$$

$$\frac{\partial\ lnCU}{\partial\ lnP_j} = \frac{\partial lnY}{\partial lnP_j} - \frac{\partial lnY^*}{\partial lnP_j} \gtreqless 0 \qquad j = E, M \tag{3.2.5}$$

$$\frac{\partial\ lnCU}{\partial\ lnW} = \frac{\partial lnY}{\partial lnW} - \frac{\partial lnY^*}{\partial lnW} \gtreqless 0$$

$$\frac{\partial\ lnCU}{\partial\ lnT} = \frac{\partial lnY}{\partial lnT} - \frac{\partial lnY^*}{\partial lnT} \gtreqless 0.$$

These equations show that the elasticity of capacity utilization, with respect to an exogenous variable, is expressed by two terms: the effect on the current level of output given the output capacity , and the effect of the output capacity given the current level of output. In this case, whichever effect is greater will determine whether capacity utilization will increase or decrease (for more details, see Kim (1999)). It can also be shown that the semi-elasticity of capacity utilization with respect to capital utilization is as follows:

$$\frac{\partial\ lnCU}{\partial\ u} = \frac{\partial\ lnY}{\partial u} - \frac{\partial lnY^*}{\partial u} \gtreqless 0.$$

I formulate the user cost of capital using Gale and Orszag (2005) as follows:

$$P_K = \frac{r - \pi + \delta(u)}{1 - \tau}\ (1 - \tau z), \tag{3.2.6}$$

where r is the nominal interest rate and π is the expected rate of inflation. In this equation, τ and z are the statutory corporate tax rate and the present value of depreciation deductions on a one-dollar investment, respectively. I consider the depreciation rates (δ) as a function of capital utilization (u) following the theoretical results of Taubman and Wilkinson (1970). Their results show that capital utilization depends on factor prices which, in turn, affect the depreciation rate of capital. As such, whenever there is evidence of a shift in factor prices, the depreciation rate should not be constant. The logarithmic form of (3.2.6) is given by:

$$lnP_K = ln(r - \pi + \delta(u)) + ln(1 - \tau z) - ln(1 - \tau). \tag{3.2.7}$$

Differentiating (3.2.7) with respect to r can be written as

$$\frac{\partial \ lnP_K}{\partial \ r} = \frac{1}{r - \pi + \delta(u)} \gtreqless 0. \tag{3.2.8}$$

Using (3.2.4) and (3.2.8) the semi–elasticity of capacity utilization with respect to the interest rate is

$$\frac{\partial \ lnCU}{\partial \ r} = -\frac{\partial lnY^*}{\partial lnP_K}\frac{\partial lnP_K}{\partial r} \gtreqless 0. \tag{3.2.9}$$

This expression shows that an increase in interest rates can have either positive or negative effects on capacity utilization. I now turn to the data to determine these effects.

3.3 Empirical Analyses

3.3.1 Data

Time series data for U.S. industries on the NAICS (North American Industry Classification System) three-digit code list is drawn from different sources for the period 1975–2011. The annual industrial-production (IP) index and capacity-utilization data are obtained from the Board of Governors of the Federal Reserve. The IP index measures real output at the three-digit industry-level as a percentage of real output in a base year.[9] The Federal Reserve Board constructs estimates of capacity utilization in a given industry by dividing an output index by a capacity index. Data on total real capital stock (in millions of USD) and total capital expenditure (in millions of USD) are obtained from the NBER-CES (National Bureau of Economic Research–Center for Economic Studies) Manufacturing Industry Database.[10] I calculate the values for total real investment by dividing the total capital expenditure by an investment deflator scale (1997=1). I calculate the depreciation rate for each industry, backing them out of the standard perpetual inventory equation as follows:

$$K_t = (1 - \delta(u_{Kt-1}))K_{t-1} + I_t, \tag{3.3.1}$$

where the net stock of fixed capital, at any given time, is the cumulative value of gross investment minus the aggregate value of past depreciation. Put differently, the machines that are available for production at time t are those that existed during the last period plus those that are producing and operating at t, minus those that are broken down.[11] Since the total real capital stock and the total capital expenditures are not available for the years that follow 2011, it was necessary to restrict the time period under study to 1975 to 2011. Rearranging (3.3.1), I calculate the depreciation

[9] I calculate the IP index for Transportation Equipment industry as an average of IP index in Motor Vehicles and Parts industries and Aerospace and Miscellaneous Transportation industries.

[10] The data is from http://www.nber.org/nberces/ comes at six–digit manufacturing industries and I calculated the aggregate data at three-digit level.

[11] I do not use Capital Expenditure Survey because it does not include information about depreciation and includes just two–digit manufacturing industries.

rate as follows:

$$\delta(u_{K_{t-1}}) = 1 - \frac{I_t - K_t}{K_{t-1}}. \tag{3.3.2}$$

Nadiri and Prucha (1993) estimated the depreciation rate of physical capital in manufacturing, as a whole, at 0.059, which is close to the depreciation rates I calculated for different manufacturing industries, using (3.3.2). Applying (3.3.2) will recreate the missing values for the depreciation rates in 2011. I estimate the imputed values for that year in order to have a balanced panel. Energy (E) and materials (M) are intermediate inputs that are purchased from domestic industries and foreign sources and consumed by industries in the process of producing gross output. Chain-type price indices for energy (P_E) and materials (P_M) are obtained from the Gross-Domestic-Product-by-Industry data series (including KLEMS data) from the Bureau of Economic Analysis (BEA).[12] Since KLEMS data are for the period 1997 to 2011, I use Dale Jorgenson's annual KLEMS data for the years prior to 1997. These data are based on the 2-digit standard industrial classification (SIC), which I cross-reference and match with the 3-digit NAICS industries in this study. Average annual pay (W) for industries are from the Bureau of Labor Statistics.[13] These data are available by ownership group.[14] I employed data that is related to the private sector and is calculated according to the real values of wages and capital stock by dividing the

[12] Based on BEA: "KLEMS (K-capital, L-labour, E-energy, M-materials, and S-purchased services) refers to broad categories of intermediate inputs that are consumed by industries in their production of goods and services".

[13] http://www.bls.gov/cew/datatoc.htm

[14] Ownership group can be international, local, state, federal, total government or private.

current values by the industrial-production index (1997). The effective federal funds rate (FFR) and the inflation rate are obtained from Federal Reserve statistics.

Capital utilization (u) is another variable used in our estimation. Since u is not directly observable, some measure for u must be used. I used the proxy of Greenstone et al. (2010) for capital utilization, which is the ratio of the dollar value of energy usage to the capital stock. The dollar value of energy usage is a good measure for capital utilization, since it increases in the use in line with the use of capital stock. The total cost of energy was obtained from the NBER-CES manufacturing industry database. This cost includes the cost of electricity and fuel.

3.3.2 Descriptive Statistics

Table 3.2 shows the correlation between the variables. The unconditional correlations show that capacity utilization and the FFR move in the same direction with a moderate correlation (0.24). There is a positive correlation equal to 0.28 between capacity utilization and capital utilization. The price of energy shows the highest correlation with capacity utilization over the study period, and is negative. Table 3.3 shows the descriptive statistics for capacity utilization in each industry over the sample period, sorted by their mean capacity utilization, from largest to smallest. The table denotes a remarkable heterogeneity in capacity utilization across industries. Paper industries and leather, and allied product industries have the highest and lowest capacity utilizations, with averages of 86.4 and 72.12, respectively. The data also show that the average capacity utilizations of nonmetallic mineral products, and leather and allied products industries have the highest variations from their means over the period, with standard deviations of 9.16 and 9.02, respectively. The food manufacturing industry has the lowest variation, during the period 1975 to 2011, with a standard deviation of 2.14.

3.3.3 Empirical Specification

In this section, I estimate the relationship between capacity utilization and interest rates, while controlling for a variety of other variables as discussed above. I use the variations across industries and over time to investigate the relationship between capacity utilization and interest-rate changes. There are a number of considerations that motivate the baseline specification, which is shown below:

$$lnCU_{it} = \begin{cases} \alpha_i + z'_{it}\alpha + \gamma_1 T + \eta_1 Dummy + u_{it} & \text{(3.3.3a)} \\ \\ \beta_i + \phi r_t + z'_{it}\beta + \gamma_2 T + \eta_2 Dummy + v_{it}, & \text{(3.3.3b)} \end{cases}$$

where (3.3.3a) shows the baseline specification without interest rates, and (3.3.3b) shows the baseline specification with interest rates included as an additional explanatory variable. As it is shown in (3.2.7), there are four factors that affect user user cost of capital: fluctuations in the interest rate, the inflation rate, depreciation, or tax rates. For this reason, using user cost of capital by itself does not allow us to separate interest rate effect from other factors. Including the interest rate as an additional explanatory variable allows us to investigate the direct effect of interest-rate fluctuations on capacity utilization. The indirect effect of the interest rate fluctuation is through user cost of capital or utilization of capital which are included in the model.

The dependent variable, $lnCU$, is the natural logarithm of capacity utilization. The subscript i refers to manufacturing industries (i=1, ..., 21) and t is time (t=1975, ..., 2011). α_i and β_i are simply the fixed- effects. z'_{it} is a K-dimensional row vector of the time-varying explanatory variables. α and β are K-dimensional column vectors of the parameters. Table 3.1 shows the explanatory variables of vector z_{it}.

Table 3.1: Explanatory Variables of vector z_{it}

Symbol	Desc.
IP_{it}	Industrial output
$P_{E\,it}$	Index price of energy
$P_{M\,it}$	Index price of material
$P_{K\,it}$	User cost of capital
W_{it}	Wages
K_{it}	Capital stock
u_{it}	Utilization rate of Capital

T shows the time trend. The $Dummy$ variable captures the recessionary period and is equal to 1 for the years 2008 and afterward, and 0 otherwise. u_{it} and v_{it} are idiosyncratic error terms. I consider two different measures of the interest rate (r_t): the FFR for the baseline model and the treasury inflation-indexed security ($TIPS$) for the robustness check. Since businesses react to changes in the nominal interest rate and not just to changes in real costs, I initially estimate the model by adding the nominal interest rate (FFR) as a regressor and do a subsequent estimate by adding real costs ($TIPS$).[15]

[15] For example see. Akhtar (1983)

To explore the relationship between capacity utilization and interest rates, I made use of variations across manufacturing industries, over time, by analyzing the two-stage least squares method (2SLS), using instrumental variables for output to address the endogeneity problem in the estimation. The instruments used are the industrial output with one lag, the dollar value of energy usage, and a time trend.[16]

As I previously mentioned, some values for the depreciation rate are missing, which leads to missing values for the rental price of capital (P_K) and an unbalanced panel. Since the panel has one continuous variable with missing values, I use a single-regression imputation. In this method, the imputed value is predicted from a regression equation. To decide which variables should be included in the imputation model, I follow the most common recommendation, which is that the imputation model should contain the same variables that are in the analytic model, including the dependent variable. Otherwise, the relationships wherein variables are omitted will be biased toward zero. This is due to the assumption of non-correlation between the imputed values and the omitted variables (see Rubin (1996); Enders (2010)).

Table 3.4 indicates a robust estimation of the relationship between capacity utilization and the factors that underlie it, using a two-stage least squares (2SLS) regression for U.S. manufacturing industries.[17] The first column shows the estimation results, without the interest rate; the second columns shows the estimation results, using the interest rate as an explanatory variable to investigate how sensitive the capacity

[16] I test the validity of my instruments by checking week-, over- and under-identification using Kleibergen-Paap rk Wald F, Hansen J, and Kleibergen-Paap rk LM statistics, respectively. The results of these tests are available upon request.

[17] Robust estimation allows me to consider the effect of persistency of the capacity utilization on the estimated parameters.

utilization ratio is to interest-rate changes. The semi-elasticity of capacity utilization with respect to the FFR appears to be very small (0.003). Both estimations suggest a positive and insignificant coefficient for industrial production. The results of both of the estimated equations indicate that the price of energy has an adverse and significant effect on capacity utilization. This is in contrast to Kim (1999) results, which find that energy prices have a stimulating effect on capacity utilization. However, earlier studies show that energy shocks had an adverse impact on capacity utilization during the 1970s. As it is shown in (3.2.5), there is no theoretical reason for predicting either positive or negative effects of input prices. However, Winston (1974) shows that an increase in wages tends to reduce capacity utilization. Obviously, this would not be the case if labour and capital were complements. The coefficient of wages is positive and significant under the specification with the interest rate, but insignificant under the specification without the interest rate. The price of capital has a correct sign but an insignificant impact on capacity utilization.

My results suggest that capital stock has a negative but insignificant effect on capacity utilization. On the contrary, a higher level of capital utilization will stimulate capacity utilization. The dummy variable, which captures the recessionary period (2008 to 2011), displays a negative and statistically significant effect.

3.3.4 The industry effects

Appendix B.1 shows capacity utilization in each manufacturing industry. As the figures show, there is a considerable variation in capacity-utilization rates both across industries and over years within industries. To clarify the direct effect of interest rates, I next investigate its impact on each industry, separately. The first column of Table 3.5 shows the estimation results using the *FFR*. The results suggest that, interest-rate movements have a significant effect on the capacity utilization of fifteen industries. Looking at the industry effects, it is clear that the overall policy effects are significantly larger in leather and allied products, computer and electronic products, and beverage and tobacco products industries. Among all industries, the food industry is the only one wherein an increase in interest rates leads to a decline in capacity utilization. One possibility is that firms in this industry are capable of adjusting their production quickly in response to interest-rate changes. The results show that the contemporaneous semi-elasticity of capacity utilization with respect to the federal funds rate is not significant in apparel, chemical, primary metal, and fabricated metal products, machinery, and miscellaneous industries.

Following the results of Baghestani (2008) for the highly significant effect of the federal funds rate with lags of six and eight quarters on capacity utilization in the manufacturing sector, I investigate the lagged effects of the interest rate on capacity utilization. Table 3.5 (last two columns) shows the estimation results that use the federal funds rate as a regressor with one and two lags. The one-period lagged *FFR* specification shows significant effects on capacity utilization in fifteen industries, while under the two-period-lagged *FFR* specification, the number of industries with a significant coefficient goes up (sixteen industries). The estimation results show that a one-period-lagged *FFR* has a reverse significant effect on capacity utilization only in four industries, which include food, fabricated metals products, machinery, and transportation equipment. In the two-period-lagged *FFR* specification, the number of manufacturing industries wherein the *FFR* has a positive and statistically significant effect falls off. Under this specification, the interest rate has a depressing effect on the capacity utilization of six industries, including food manufacturing, primary metals, fabricated metal products, machinery, and electrical equipment, appliances and components, and transportation equipment. In terms of magnitude, changes in the interest rate have the greatest positive effects on capacity utilization in computers and electronic products, and beverages and tobacco products industries in both estimations, i.e. with one and two lags. The greatest reverse impact on capacity utilization with the one-lag estimation is on the food processing industry. Capacity utilization here and in machinery industries shows the greatest negative reaction to changes in the interest rate in the estimation with two lags, which is equal to -0.014 and highly significant. Figure 3.2 summarizes these results.

3.3.5 Robustness Checks

In this section, I examine the robustness of my results, using three different exercises. First, I apply two alternative imputation methods: predictive mean matching for continuous variables (PMM) and the monotone imputation for the missing data.[18] My estimations show that both of these imputation methods generate similar results. In the second exercise, I use the Wu–Xia shadow rate, instead of the *FFR*, for the years 2009 to 2011, and re-estimate the models. However, the results remain quite

[18] PMM is an alternative way of imputing missing values of a continuous variable which identifies one or more neighbors with similar estimated values using regression methods (Roderick, 1988). Monoton imputation is a non-iterative method which can be used when the missingness pattern is monotone (Rubin, 1987).

similar, since the data is changed for just three years.[19] In the last exercise, I use another regressor to analyze the direct effect of the interest rate changes on capacity utilization. Subsequently, I employ 5- and 10-year treasury inflation-indexed securities (*TIPS*) as extra explanatory variables. The *TIPS* protects investors against inflation. Since the rental price of capital is measured by the consumer price index (CPI), while the interest rate remains fixed, I define it as

$$P_K = TIPS_t + \delta(h_{Kt}). \tag{3.3.4}$$

Table 3.6 shows the estimation results using the *FFR*, the 5-year *TIPS*, and the 10-year *TIPS* for the period 2005–2011. Since the *TIPS* data are available from 2003, picking this period allows us to compare the results using different regressors with zero, one, and two lags. For the period 2005–2011, the *FFR*, the 5-year *TIPS*, and the 10-year *TIPS* show negative and highly significant effects on capacity utilization. In terms of magnitude, however, the effect is greater in the estimation that uses the 10-year *TIPS*. In contrast to the estimated results for the period 1975–2011, shown in Table 3.4, the price of energy does not show any significant impact on capacity utilization in all three estimated model. From the end of 2002 to the middle of 2008, the U.S. economy experienced a significant increase in oil prices. This increase is comparable in magnitude to the first two OPEC shocks, but Hooker 1996, 2002; Blanchard and Gali 2010 have shown that oil-price shocks have had smaller macroeconomic effects since the early 1980s. Their results show that the positive response of

[19] The results are available upon request.

core inflation to oil-price shocks has sharply diminished over time; their results also show that the negative responses of output and employment to increased oil prices have almost vanished. This explains the insignificant effect of energy prices in my estimation model. In all specifications, the price of materials shows a positive and significant impact on capacity utilization. The results show that when capital stock is more expensive, this leads to lower capacity utilization. An increase in the amount of capital stock does not show a significant effect on capacity utilization in all cases. An increase in the price of labour causes a stimulating effect on capacity utilization for all specifications. A more intense utilization of the the existing capital stock causes higher levels of capacity utilization in all scenarios. The time trend, which captures the influences of changes in technology, shows negative coefficients that are statistically significant in the estimated models with the 5- and 10-year *TIPS*. The dummy variable, which captures the recessionary period (2008—2011), shows a negative and statistically significant effect in all of the estimated models. Overall, the results suggest a stronger effect of monetary policy in the estimated models with the 5- and 10-year *TIPS*.

Tables 3.7 and 3.8 show the results of the estimations for the period 2005–2011 with a one- and two-year lag, respectively. Comparing the estimations results suggests that the direct interest-rate effect is higher in the case of the 10-year *TIPS* as the regressor. However, the other coefficients are quite similar. The negative semi-elasticity of capacity utilization with respect to the interest rate is greater in the case that uses the related regressor with a 2-year lag. In both the 5-year *TIPS* and 10-year *TIPS* specifications with a one- or two-year lag, an increase in the price of materials or labour would encourage higher capacity utilization. In all specifications with a one- or two-year lag, an increase in the user cost of capital will decrease capacity utilization. An increase in the capital stock or in investment activity does not lead to a significant effect on capacity utilization in all cases. However, a more intense utilization of the existing capital stock causes higher levels of capacity utilization in all scenarios. A caution for this short series of 5- and 10-year *TIPS* is that estimating the models by industry and using these regressors can be very noisy. For this reason I do not provide estimations by industry, but rather across industries.

The theory suggests that a drop in the interest rate brings down the rental cost of capital which, in turn, encourages manufacturing industries to borrow more capital to increase production. However, my results show that, in most of the industries reviewed, an interest-rate cut does not encourage an increase in production and capacity utilization in the same time period; rather, it takes two periods for the effects of this policy to appear.

3.4 Conclusions

In this paper, I conducted an economic analysis of capacity utilization and its determinants, using the 2SLS fixed-effects estimation in a panel setting, for U.S. manufacturing industries, over the period 1975–2011. The results show that there is considerable cross-industry heterogeneity in the effects of interest-rate changes. Among industries, food manufacturing is the only one that reacts to a cut in interest rates with an increase in capacity utilization in the same period. Since this industry accounts for less than ten percent of total manufacturing production, a cut in the interest rate will only stimulate a small portion of manufacturing production in the short run. Capacity utilization in machinery, fabricated products, and transportation equipment industries shows a negative response to changes in the interest rate after one period. Primary and electrical equipment, appliance, and component industries negatively respond after two periods.

In contrast to previous studies, I find no evidence that differences in the sensitivity of capacity utilization to interest-rate changes can be explained by the durability of the goods produced in the industry. In terms of magnitude, the leather and allied products industries (which belong to the category of non-durable manufacturing industries), and computers and electronic products (which belong to durable manufacturing industries), respectively, show the greatest sensitivity to interest-rate changes. Regardless of which factor is used as the regressor for the interest rate, the semi-elasticity of capacity utilization with respect to interest-rate changes is negative and highly significant over the period 2005–2011. However, this sensitivity is positive in the estimation results for the period 1975–2011. Evidence from U.S. manufacturing industries shows that the price of energy has a depressing effect on the capacity utilization of manufacturing industries over the period 1975–2011. However, the estimation results for the period 2005–2011 do not show any significant effect of energy prices on capacity utilization. Comparing these results highlights that the role of energy prices on capacity utilization has sharply diminished over time. This suggests that policies that aimed to reduce the price of energy did not have any effect on capacity utilization in recent years.

The price of materials shows a stimulating effect on capacity utilization in almost in all of the estimated models. The estimation results also suggest that an increase in wages can result in an increase in capacity utilization. Capital utilization always has a positive effect on capacity utilization. In many industries, an increase in the interest rate has a stimulating effect on capacity utilization. This suggests that many firms make use of their current stock of capital more intensively in response to an increase in the user cost of capital and, consequently, increase their capacity utilization and production. Overall, my results show evidence that policy instruments that decrease interest rates will not always stimulate capacity utilization.

References

Akhtar, M. A.: 1983, Effects of interest rates and inflation on aggregate inventory investment in the United States, *The American Economic Review* **73**(3), 319–328.

Alvarez-Lois, P. P.: 2005, Production inflexibilities and the cost channel of monetary policy, *Economic Inquiry* **43**(1), 170–193.

Baghestani, H.: 2008, Predicting capacity utilization: Federal Reserve vs time-series models, *Journal of Economics and Finance* **32**, 47–57.

Belton, W. J. and Cebula, R. J.: 2000, Capacity utilization rates and unemployment rates: are they complements or substitutes in warning about future inflation?, *Applied Economics* **32**(12), 1521–1532.

Berndt, E. R. and Fuss, M. A.: 1989, Economic capacity utilization and productivity measurement for multi-product firms with multiple quasi-fixed inputs, *Working Paper 2932*, National Bureau of Economic Research.

Berndt, E. R. and Morrison, M. A.: 1981, Capacity utilization measures: Underlying economic theory and an alternative approach, *American Economic Review* **71**(2), 48–52.

Blanchard, O. J. and Gali, J.: 2010, *International Dimensions of Monetary Policy*, University of Chicago Press, chapter The macroeconomic effects of oil shocks: Why are the 2000s so different from the 1970s?, pp. 373–421.

Boileau, M. and Normandin, M.: 2003, Capacity utilization, superior information, and the business cycle, *Journal of Macroeconomics* **25**(3), 283–309.

Cassels, J. M.: 1937, Excess capacity and monopolistic competition, *Quarterly Journal of Economics* **51**(3), 426–443.

Dotsey, M. and Stark, T.: 2005, The relationship between capacity utilization and inflation, *Business Review* (Q2), 8–17.

Durlauf, S. and Blume, L. E. (eds): 2008, *The new Palgrave: a dictionary of economics*, 2nd edition edn, Palgrave Macmillan Ltd, chapter Capital Utilization.

Emery, K. M. and Chang, C.-P.: 1997, Is there a stable relationship between capacity utilization and inflation?, *Economic and Financial Policy Review* (Q I), 14–20.

Enders, C. K.: 2010, *Applied missing data analysis*, New York: Guilford.

Finn, M. G.: 1996, A theory of the capacity utilization/inflation relationship, *FRB Richmond Economic Quarterly* **82**(3), 67–86.

Gale, W. G. and Orszag, P. R.: 2005, Deficits, interest rates, and the user cost of capital: A reconsideration of the effects of tax policy on investment, *National Tax Journal* **58**(3), 409–426.

García-Schmidt, M. and Woodford, M.: 2016, Are Low Interest Rates Deflationary? A Paradox of Perfect-Foresight Analysis, *Working Papers Central Bank of Chile 797*, Central Bank of Chile.

Garner, C. A.: 1994, Capacity utilization and U.S. inflation, *Federal Reserve Bank of Kansas City, Economic Review* **79**(4), 1–21.

Garofalo, G. A. and Malhotra, D. M.: 1997, Regional measures of capacity utilization in the 1980s, *Review of Economics and Statistics* **79**(3), 415–421.

Greenstone, M., Hornbeck, R. and Moretti, E.: 2010, Identifying agglomeration spillovers: Evidence from winners and losers of large plant openings, *The Journal of Political Economy* **118**(3), 536–598.

Greenwood, J., Hercowitz, Z. and Huffman, G. W.: 1988, Investment, capacity utilization, and the real business cycle, *The American Economic Review* **78**(3), 402–417.

Hooker, M. A.: 1996, What happened to the oil price-macroeconomy relationship?, *Journal of Monetary Economics* (38), 195–213.

Hooker, M. A.: 2002, Are oil shocks inflationary? Asymmetric and nonlinear specifications versus changes in regime, *Journal of Money, Credit, and Banking* (34), 540–561.

Kim, H. Y.: 1999, Economic capacity utilization and its determinants: Theory and evidence, *Review of Industrial Organization* **15**(4), 321–339.

Klein, L. R.: 1960, Some theoretical issues in the measurement of capacity, *Econometrica* **28**(2), 272–286.

Krüger, J.: 2008, Capacity utilization and technology shocks in the US manufacturing sector, *International Review of Applied Economics* **22**, 287–298.

Lovell, C. A. K.: 1968, Capacity utilization and production function estimation in postwar american manufacturing, *The Quarterly Journal of Economics* **82**(2), 219–239.

Morrison, C. J.: 1985, On the economic interpretation and measurement of optimal capacity utilization withanticipatory expectations, *The Review of Economic Studies* **52**(2), 295–310.

Nadiri, M. I. and Prucha, I. R.: 1993, Estimation of the depreciation rate of physical and R&D capital in the U.S. total manufacturing sector, *National Bureau of Economic Research* .

Peersman, G. and Smets, F.: 2005, The industry effects of monetary policy in the euro area, *The Economic Journal* **115**(503), 319–342.

Roderick, J. A. L.: 1988, Missing-data adjustments in large surveys, *Journal of Business & Economic Statistics* **6**(3), 287–96.

Rubin, D. B.: 1987, Multiple imputation for nonresponse in surveys, *John Wiley & Sons, Inc., Hoboken, NJ, USA.*

Rubin, D. B.: 1996, Multiple imputation after 18 plus years, *Journal of the American Statistical Association* **91**(434), 473–489.

Shapiro, M. D.: 1986, Capital utilization and capital accumulation: Theory and evidence, *Journal of Applied Econometrics* **1**(3), 211–234.

Taubman, P. and Wilkinson, M.: 1970, User cost, capital utilization and investment theory, *International Economic Review* **11**(2), 209–215.

Winston, G. C.: 1974, The theory of capital utilization and idleness, *Journal of Economic Literature* **12**, 1301–1320.

Wu, J. C. and Xia, F. D.: 2016, Measuring the macroeconomic impact of monetary policy at the zero lower bound, *Journal of Money, Credit and Banking* **48**(2-3), 253–291.

Table 3.2: Correlation

	CU	IP	P_E	P_M	W	P_K	K	u	FFR
CU	1.000								
IP	0.044	1.0000							
P_E	−0.332	0.269	1.000						
P_M	−0.085	0.140	0.745	1.000					
W	−0.111	0.809	0.331	0.124	1.000				
P_K	0.152	0.041	−0.341	−0.398	−0.003	1.000			
K	− 0.045	0.349	0.216	0.204	0.578	−0.104	1.000		
u	0.283	−0.104	−0.167	−0.047	−0.226	0.104	−0.019	1.000	
FFR	**0.239**	−0.238	−0.535	−0.447	−0.314	0.622	−0.142	0.147	1.000

Table 3.3: Descriptive Statistics of Capacity Utilization

Manufacturing Industries	Mean	Std. Dev.	Min	Max
Paper	86.362	3.840	77.149	92.120
Petroleum & coal products	85.132	5.765	71.206	95.164
Plastics & rubber products manufacturing	81.947	7.051	61.535	91.324
Food	81.927	2.144	77.901	85.567
Electrical equipment, appliance, & component	81.331	6.097	68.260	91.366
Textile product mills	80.728	8.399	58.746	93.551
Printing & related support activities	80.476	7.273	60.225	90.484
Textile mills	79.481	8.566	55.175	92.334
Apparel	79.018	5.001	66.372	86.703
Primary metal	78.235	8.826	55.168	90.898
Computer & electronic product	77.831	5.771	60.842	87.494
Beverage & tobacco product	77.248	5.573	66.594	85.827
Chemical	77.203	4.107	67.791	84.090
Machinery	76.956	7.275	60.487	90.136
Fabricated metal product	76.660	5.105	64.635	86.575
Wood product	76.312	8.251	51.180	86.022
Miscellaneous	76.035	3.064	67.658	81.881
Furniture and related product	75.665	6.191	58.381	86.024
Nonmetallic mineral product	74.837	9.597	45.758	86.520
Transportation equipment	74.108	6.156	55.883	83.089
Leather & allied product	72.120	9.016	48.400	83.905

Table 3.4: Baseline specifications with and without interest rate

Regressor	Without interest rate	With interest rate
Constant	3.650***	3.594***
	(0.762)	(0.754)
FFR		0.003*
		(0.002)
$ln(P_K)$	−0.010	−0.014
	(0.010)	(0.010)
u	0.034***	0.036***
	(0.010)	(0.011)
ln(IP)	0.019	0.012
	(0.039)	(0.039)
$ln(P_E)$	−0.130***	−0.155***
	(0.034)	(0.038)
$ln(P_M)$	0.192***	0.192***
	(0.036)	(0.037)
ln(W)	0.071	0.081*
	(0.048)	(0.048)
ln(K)	−0.015	−0.008
	(0.070)	((0.070)
T	−0.002	−0.001
	(0.002)	(0.002)
Dummy	−0.113***	−0.110***
	(0.018)	(0.019)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. n=755

Table 3.5: Specification by Manfacturing Industries (1975–2011)

Regressor	FFR	FFR_{t-1}	FFR_{t-2}
Constant	3.667***	3.618***	3.052***
	(0.812)	(0.820)	(0.702)
$ln(IP)$	0.023	0.040	0.002
	(0.036)	(0.040)	(0.034)
$ln(P_E)$	−0.164***	−0.062**	−0.069**
	(0.033)	(0.030)	(0.027)
$ln(P_M)$	0.236***	0.222***	0.238***
	(0.048)	(0.044)	(0.041)
$ln(P_K)$	−0.014	0.001	0.005
	(0.010)	(0.009)	(0.008)
$ln(K)$	−0.066	−0.063	−0.010
	(0.073)	(0.072)	(0.067)
$ln(W)$	0.144***	0.105*	0.134***
	(0.051)	(0.055)	(0.052)
u	0.039***	0.030***	0.033***
	(0.011)	(0.010)	(0.010)
T	−0.002	−0.007	−0.009***
	(0.002)	(0.002)	(0.002)
Dummy	−0.104***	−0.109***	−0.100***
	(0.019)	(0.018)	(0.019)
FFR (Food)	−0.007***	−0.013***	−0.014***
	(0.003)	(0.002)	(0.002)
FFR (Beverage & tobacco product)	0.024***	0.021***	0.017***
	(0.002)	(0.002)	(0.002)

Regressor	FFR	FFR_{t-1}	FFR_{t-2}
FFR (Textile mills)	0.020^{***}	0.014^{***}	0.012^{***}
	(0.004)	(0.004)	(0.004)
FFR (Textile product mills)	0.018^{***}	0.014^{***}	0.013^{***}
	(0.002)	(0.002)	(0.002)
FFR (Apparel)	0.005	0.003	0.003
	(0.005)	(0.006)	(0.005)
FFR (Leather & allied product)	0.025^{***}	0.019^{***}	0.016^{***}
	(0.006)	(0.006)	(0.006)
FFR (Wood product)	0.016^{***}	0.011^{***}	0.008^{***}
	(0.002)	(0.002)	(0.002)
FFR (Paper)	0.004^{**}	0.004^{***}	0.004^{**}
	(0.002)	(0.002)	(0.001)
FFR (Printing & related support activities)	0.016^{***}	0.014^{***}	0.014^{***}
	(0.002)	(0.002)	(0.002)
FFR (Petroleum & coal products)	0.009^{*}	0.003	0.004
	(0.005)	(0.004)	(0.004)
FFR (Chemical)	0.004	0.003	0.000
	(0.003)	(0.002)	(0.002)
FFR (Plastics & rubber products)	0.011^{***}	0.007^{***}	0.006^{***}
	(0.001)	(0.001)	(0.001)
FFR (Nonmetallic mineral product)	0.015^{***}	0.011^{***}	0.006^{***}
	(0.003)	(0.002)	(0.002)
FFR (Primary metal)	0.005	-0.003	-0.009^{**}
	(0.004)	(0.004)	(0.004)
FFR (Fabricated metal product)	-0.000	-0.004^{***}	-0.008^{**}

Regressor	FFR	FFR_{t-1}	FFR_{t-2}
	(0.001)	(0.001)	(0.001)
FFR (Machinery)	0.002	-0.005^{***}	-0.014^{***}
	(0.001)	(0.001)	(0.001)
FFR (Computer & electronic product)	0.024^{***}	0.022^{***}	0.017^{***}
	(0.004)	(0.005)	(0.005)
FFR (Electrical equipment, appliance & component)	0.005^{**}	0.000	-0.004^{*}
	(0.002)	(0.002)	(0.002)
FFR (Transportation equipment)	0.002^{*}	-0.003^{**}	-0.005^{***}
	(0.001)	(0.001)	(0.001)
FFR (Furniture & related product)	0.007^{***}	0.002^{***}	0.001
	(0.001)	(0.001)	(0.001)
FFR (Miscellaneous)	0.002	-0.001	-0.001
	(0.003)	(0.003)	(0.003)

Notes: Dependent variable is $ln(CU)$. FFR(.) shows the interaction between interest rate and each industry. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.

n=755

Table 3.6: Estimation using different regressors (2005–2011)

Regressor	*Est. FFR*	*Est. 5-year TIPS*	*Est. 10-year TIPS*
Constant	-2.279	-0.506	-1.497
	(3.262)	(2.824)	(3.105)
FFR	-0.015^{***}	-0.097^{***}	-0.110^{***}
	(0.005)	(0.027)	(0.033)
ln(IP)	0.143	0.190^{**}	0.144
	(0.105)	(0.095)	(0.105)
$ln(P_E)$	0.095	0.086	0.119
	(0.179)	(0.148)	(0.162)
$ln(P_M)$	0.709^{***}	0.490^{**}	0.490^{**}
	(0.233)	(0.225)	(0.229)
$ln(P_K)$	-0.039^{***}	-0.069^{***}	-0.074^{***}
	(0.013)	(0.020)	(0.024)
ln(K)	-0.098	$-$ 0.088	-0.013
	(0.224)	(0.206)	(0.229)
ln(W)	0.583^{***}	0.412^{**}	0.449^{**}
	(0.208)	(0.203)	(0.205)
u	0.049^{**}	0.046^{**}	0.049^{***}
	(0.019)	(0.021)	(0.023)
T	-0.017	-0.055^{***}	-0.041^{***}
	(0.012)	(0.012)	(0.011)
Dummy	-0.194^{***}	-0.134^{***}	-0.128^{***}
	(0.053)	(0.034)	(0.033)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=147
FFR: $R^2_{within} = 0.80$
5-year $TIPS$: $R^2_{within} = 0.83$
10-year $TIPS$: $R^2_{within} = 0.81$

Table 3.7: Estimation using different regressors with one lag (2005–2011)

Regressor	*Est.* FFR_{t-1}	*Est. 5-year* $TIPS_{t-1}$	*Est. 10-year* $TIPS_{t-1}$
Constant	-1.682	-3.649	-3.967
	(2.964)	(3.655)	(3.749)
$\boldsymbol{FFR_{t-1}}$	-0.009^{***}	-0.026^{**}	-0.042^{**}
	(0.003)	(0.011)	(0.018)
ln(IP)	0.185^{**}	0.108	0.099
	(0.093)	(0.117)	(0.120)
$ln(P_E)$	0.096	0.324	0.337
	(0.161)	(0.213)	(0.218)
$ln(P_M)$	0.703^{***}	0.568^{**}	0.528^{**}
	(0.229)	(0.226)	(0.230)
$ln(P_K)$	-0.035^{***}	-0.078^{***}	-0.070^{***}
	(0.012)	(0.023)	(0.026)
ln(K)	-0.150	-0.001	-0.020
	(0.207)	(0.252)	(0.261)
ln(W)	0.568^{***}	0.530^{**}	0.544^{**}
	(0.204)	(0.212)	(0.214)
u	0.045^{**}	0.054^{**}	0.055^{**}
	(0.018)	(0.027)	(0.027)
T	-0.021^{*}	-0.014	-0.012
	(0.011)	(0.009)	(0.010)
Dummy	-0.124^{***}	-0.142^{***}	-0.141^{***}
	(0.035)	(0.037)	(0.037)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=147
FFR_{t-1}: $R^2_{within} = 0.81$
5-year $TIPS_{t-1}$: $R^2_{within} = 0.79$
10-year $TIPS_{t-1}$: $R^2_{within} = 0.78$

Table 3.8: Estimation using different regressors with two lags (2005–2011)

Regressor	*Est.* FFR_{t-2}	*Est. 5-year* $TIPS_{t-2}$	*Est. 10-year* $TIPS_{t-2}$
Constant	−0.458	−1.054	0.647
	(2.700)	(2.823)	(2.674)
$\boldsymbol{FFR}_{t-2}$	-0.010^{***}	-0.048^{***}	-0.140^{***}
	(0.003)	(0.013)	(0.033)
ln(IP)	0.209^{**}	0.208^{**}	0.250^{***}
	(0.086)	(0.093)	(0.088)
$ln(P_E)$	−0.035	0.166	0.062
	(0.132)	(0.159)	(0.137)
$ln(P_M)$	0.653^{***}	0.528^{**}	0.491^{**}
	(0.234)	(0.222)	(0.232)
$ln(P_K)$	-0.028^{**}	-0.070^{***}	-0.066^{***}
	(0.012)	(0.020)	(0.021)
ln(K)	−0.152	−0.131	−0.180
	(0.198)	(0.202)	(0.196)
ln(W)	0.519^{**}	0.430^{**}	0.359^{*}
	(0.206)	(0.203)	(0.209)
u	0.042^{**}	0.046^{**}	0.042^{**}
	(0.017)	(0.021)	(0.019)
T	-0.024^{**}	-0.019^{**}	-0.031^{***}
	(0.011)	(0.009)	(0.009)
Dummy	-0.068^{***}	-0.063^{***}	−0.001
	(0.026)	(0.023)	(0.021)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. n=147
FFR_{t-1}: $R^2_{within} = 0.83$ *5-year* $TIPS_{t-1}$: $R^2_{within} = 0.83$
10-year $TIPS_{t-1}$: $R^2_{within} = 0.83$

Figure 3.1: Capacity utilization before and after crisis

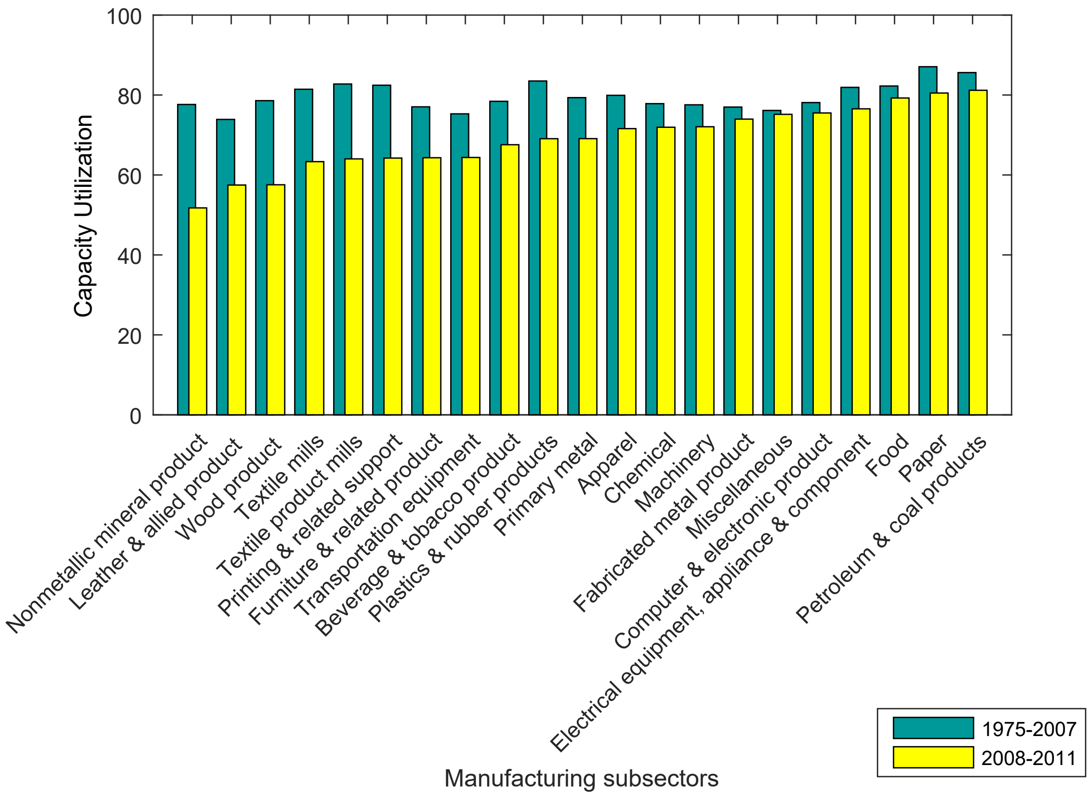
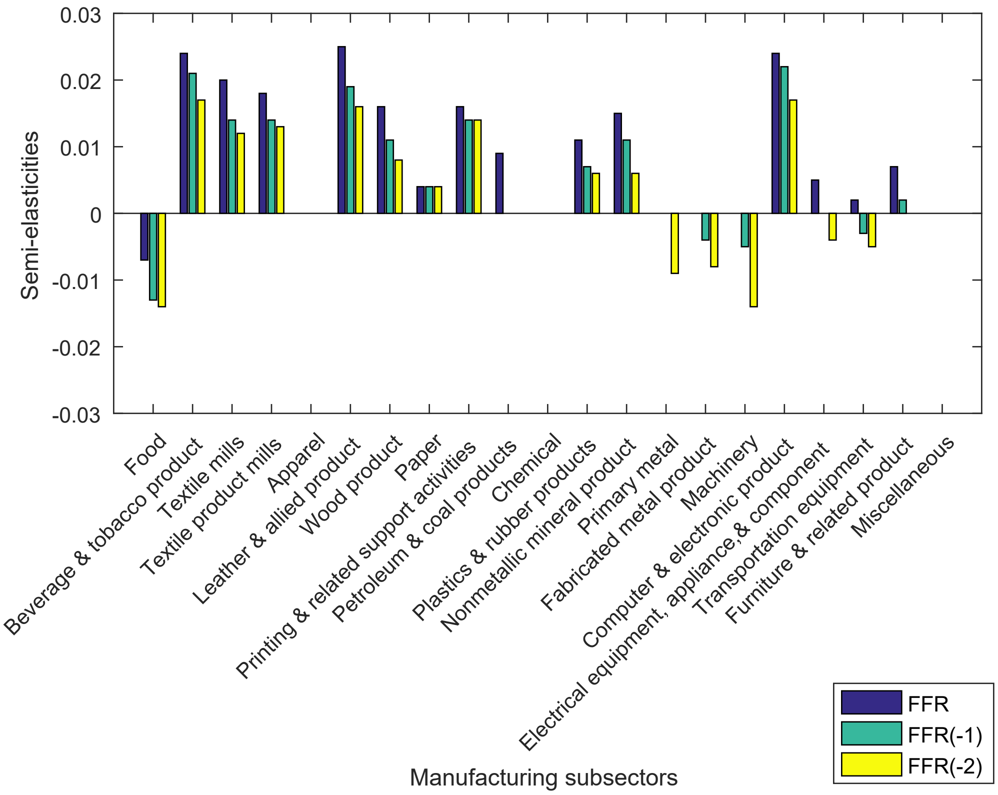


Figure 3.2: Semi-elasticity of CU respect to *FFR* with 0, 1 and 2 lags



Appendix A

Appendix for Chapter 1

A.1 Decompositions using alternative human capital indices

Table A.1: Accounting for Canada Growth, 1981-2014 (Alternative human capital measure)

		TRANSITION DYNAMICS				
	Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	Excess Idea Growth	Steady-State Growth
γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_t - \gamma_j \tilde{n}$	$\gamma_j \tilde{n}$
0.17	1.098	0.433	−0.016	0.493	0.060	0.128
	(100%)	(39.44%)	(−1.46%)	(44.90%)	(5.46%)	(11.66%)
0.18	1.098	0.433	−0.016	0.493	0.052	0.136
	(100%)	(39.44%)	(−1.46%)	(44.90%)	(4.73%)	(12.39%)
0.20	1.098	0.433	−0.016	0.493	0.037	0.151
	(100%)	(39.44%)	(−1.46%)	(44.90%)	(3.37%)	(13.75%)

Notes: This table reports the growth accounting decomposition corresponding to equation (1.3.3). The numbers in columns 2-7 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

Table A.2: Accounting for U.S. Growth, 1981-2014 (Alternative human capital measure)

		TRANSITION DYNAMICS				
	Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	Excess Idea Growth	Steady-State Growth
γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_t - \gamma_j \tilde{n}$	$\gamma_j \tilde{n}$
0.05	1.644	−0.088	−0.012	0.512	1.194	0.038
	(100%)	(−5.35%)	(−0.73%)	(31.14%)	(72.63%)	(2.31%)
0.18	1.644	−0.088	−0.012	0.512	1.096	0.136
	(100%)	(−5.35%)	(−0.73%)	(31.14%)	(66.67%)	(8.27%)
0.48	1.644	−0.088	−0.012	0.512	0.870	0.362
	(100%)	(−5.35%)	(−0.73%)	(31.14%)	(52.92%)	(22.02%)

Notes: This table reports the growth accounting decomposition corresponding to equation (1.3.3). The numbers in columns 2-7 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

Table A.3: Constant growth path decomposition, 1981-2014 (Alternative human capital measure)

			TRANSITION DYNAMICS				
		Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	G-6 R&D Intensity	Scale Effect of G-6 Labour Force
Country	γ_j	$g_{y_{jt}}$	$\frac{\alpha}{1-\alpha} g_{k_{jt}}$	$g_{\ell_{Y_{jt}}}$	$\psi_j \Delta \ell_{h_{jt}}$	$\gamma_j g_{\tilde{\ell}_A}$	$\gamma_j \tilde{n}$
Canada	0.06613	1.098	0.433	−0.016	0.493	0.138	0.050
		(100%)	(39.44%)	(−1.46%)	(44.90%)	(12.57%)	(4.55%)
U.S.	0.43334	1.644	−0.088	−0.012	0.512	0.905	0.327
		(100%)	(−5.35%)	(−0.73%)	(31.14%)	(55.05%)	(19.89%)

Notes: G-6 is defined as G-5 plus Canada.

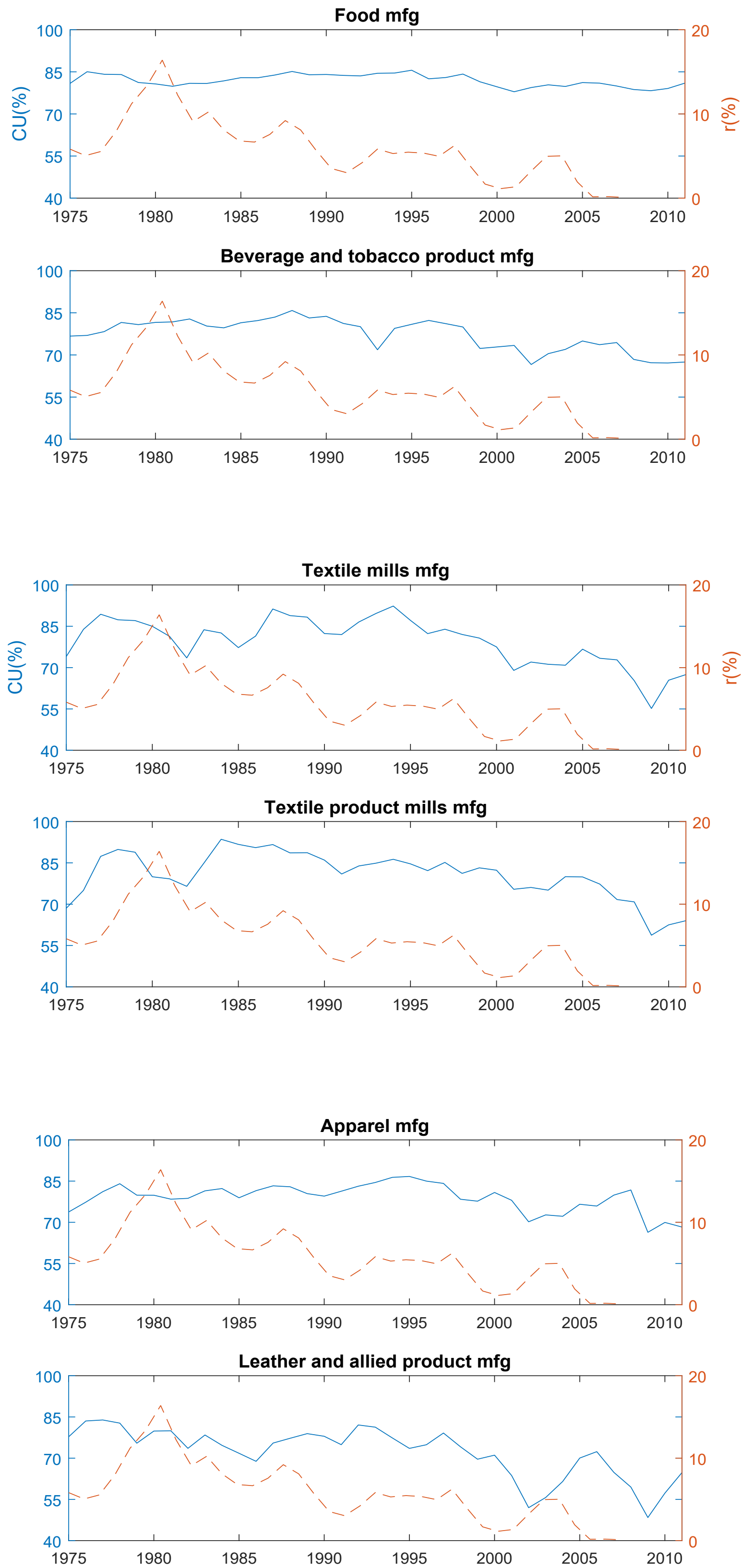
Appendix B

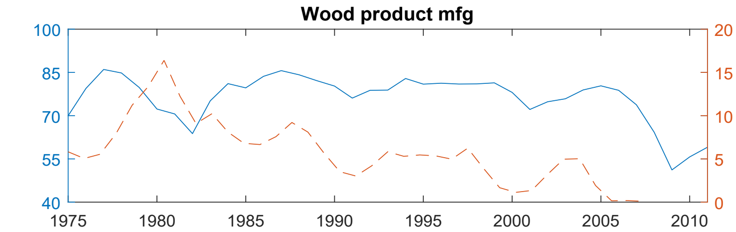
Appendix for Chapter 3

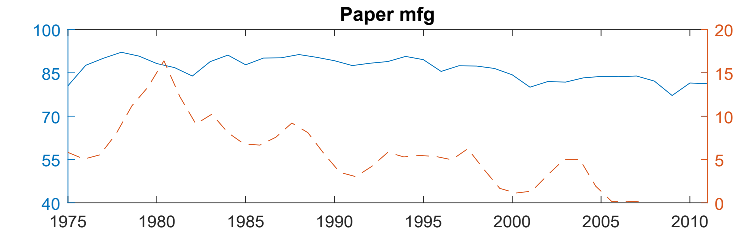
B.1 Capacity utilization and interest rates

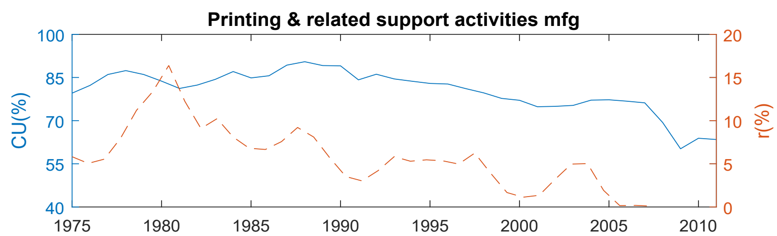
Graphs display capacity utilization in each manufacturing industry and federal funds effective rate as an indicator for interest rate over 1975–2011. The solid line in each graph shows capacity utilization over this period and the dashed line shows the interest rate. It reveals that the nature of fluctuations in capacity utilization differs across manufacturing industries.

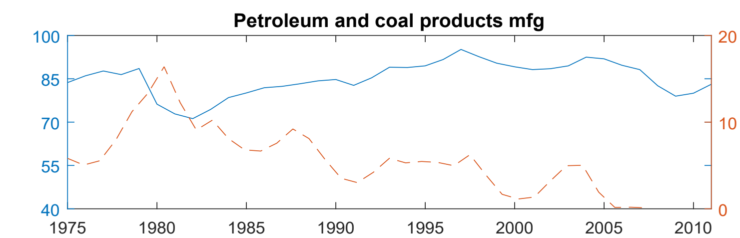
Figure B.1: Capacity utilization and interest rate

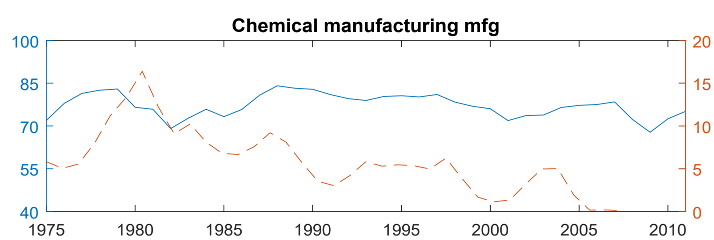


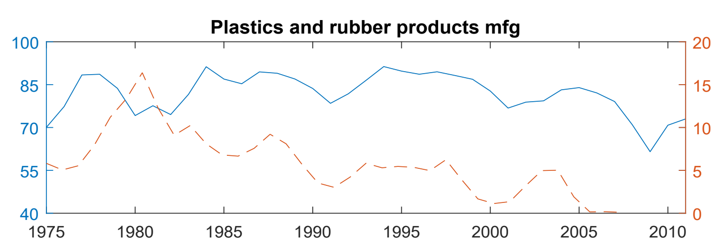

Wood product mfg

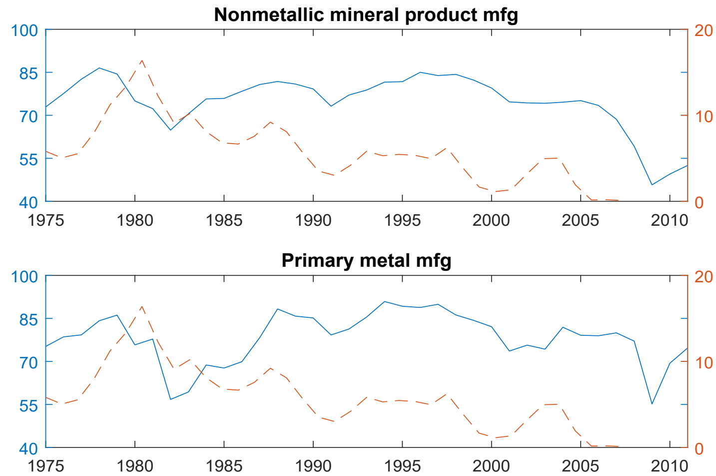

Paper mfg

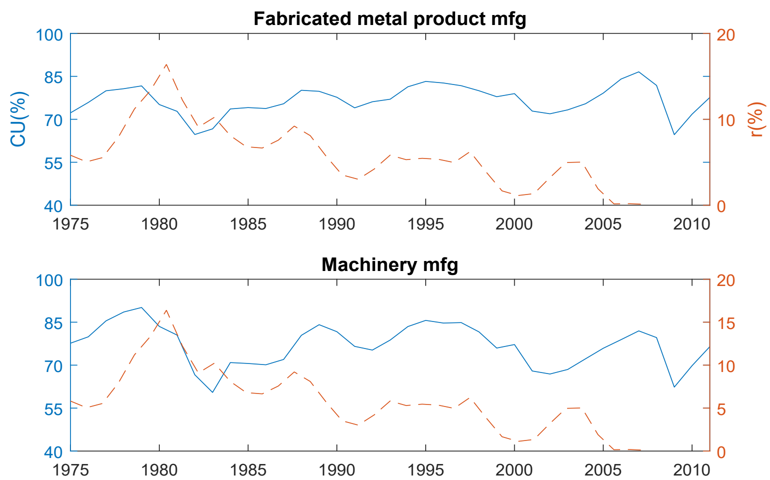

Printing & related support activities mfg
CU(%)
r(%)

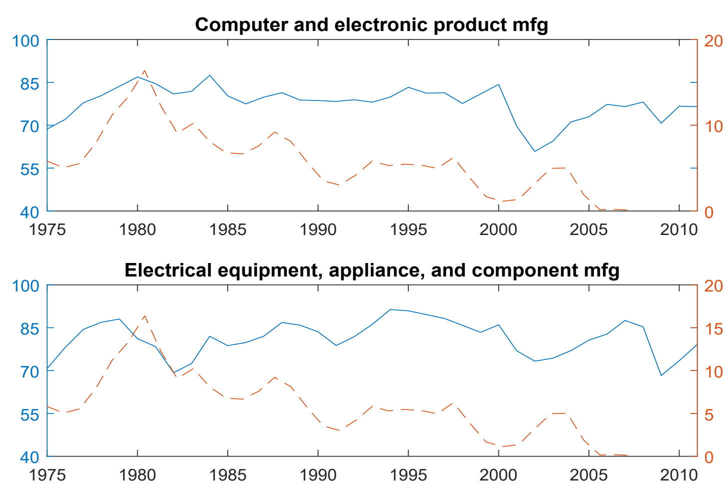

Petroleum and coal products mfg

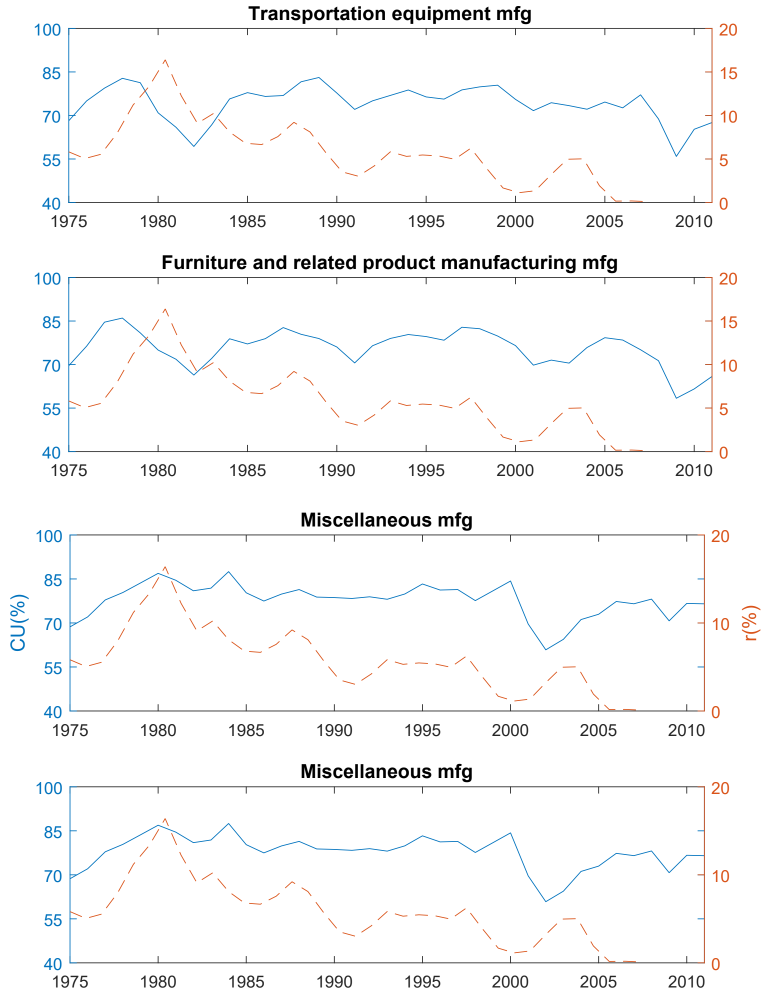

Chemical manufacturing mfg


Plastics and rubber products mfg


Nonmetallic mineral product mfg
Primary metal mfg


Fabricated metal product mfg
Machinery mfg
CU(%)
r(%)


Computer and electronic product mfg
Electrical equipment, appliance, and component mfg


Transportation equipment mfg
Furniture and related product manufacturing mfg
Miscellaneous mfg
Miscellaneous mfg
CU(%)
r(%)
100
85
70
55
40
20
15
10
5
0
1975
1980
1985
1990
1995
2000
2005
2010

B.2 Theoretical Link between r and CU

This part investigates the theoretical link between interest rates and capacity utilization using quadratic form of the cost function from Garofalo and Malhotra (1997). This form is a convenient way for presenting *SRVC* function, because it provides a closed-form expression for Y^*. The *SRVC* is given by

$$\begin{aligned} SRVC = \alpha_0 + G[\alpha_G + 0.5\gamma_{GG}\frac{G}{Y} + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T] \\ + T[\alpha_T + 0.5\gamma_{TT}T + \gamma_{TL}P_L + \gamma_{TE}P_E + \gamma_{TM}P_M + \gamma_{TY}Y] \\ + P_L[\alpha_L + 0.5\gamma_{LL}P_L + \gamma_{LE}P_E + \gamma_{LM}P_M + \gamma_{LY}Y] \\ + P_E[\alpha_E + 0.5\gamma_{EE}P_E + \gamma_{EM}P_M + \gamma_{EY}Y] \\ + P_M[\alpha_M + 0.5\gamma_{MM}P_M + \gamma_{MY}Y] \\ + Y[\alpha_Y + 0.5\gamma_{YY}Y]. \end{aligned} \tag{B.2.1}$$

The optimal level of capital services is the level of service flow from capital stock G^* under which the equilibrium condition or envelope condition is satisfied, which gives

$$P_K = -\frac{\partial SRVC}{\partial G^*}, \tag{B.2.2}$$

where P_K is rental price of capital. Using (B.2.1) and (B.2.2), P_K is defined as

$$P_K = -[\alpha_G + \gamma_{GG}\frac{G}{Y} + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T]. \tag{B.2.3}$$

With rearranging (B.2.3), the optimal level of capital is given as

$$G^* = -\gamma_{GG}{}^{-1} Y[\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + P_K]. \tag{B.2.4}$$

At the capacity level of output $SRMC = LRMC$. Then

$$\frac{\partial SRVC}{\partial Y} = \frac{\partial SRVC}{\partial Y} + \frac{\partial SRVC}{\partial G^*}\frac{\partial G^*}{\partial Y} + P_K \frac{\partial G^*}{\partial Y}. \tag{B.2.5}$$

Simplifying (B.2.5) gives the envelope condition ($-\frac{\partial SRVC}{\partial G} = P_K$). Therefore, I can estimate capacity level of output (Y^*) by inverting (B.2.4) and solving for Y as

$$Y^* = -\gamma_{GG} G^* [\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + P_K]^{-1}. \tag{B.2.6}$$

with substituting (3.2.2) and (3.2.7) in (B.2.6), the capacity level of output is

$$Y^* = -\gamma_{GG} u K [\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + r - \pi + \delta(u)]^{-1} \tag{B.2.7}$$

where $\gamma_{GG} > 0$ in order to ensure that I have a negative own price elasticity of demand for capital in long run. Substituting (B.2.7) in (3.2.1) gives capacity utilization equation as a function of the interest rate and all other variables discussed before.

$$CU = \frac{Y}{Y^*} = -\frac{Y[\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + r - \pi + \delta(u)]}{\gamma_{GG} u K} \tag{B.2.8}$$