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Abstract

We apply 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. This framework allows us to distinguish between transition dynamics and steady-state growth as well as quantify their respective contributions. We find that the bulk of the 1.1 percentage points total average Canadian growth rate of output per hour 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 0.06 percentage points. 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. We estimate a relatively low elasticity of output with respect to world research effort as the reason behind the small share of R&D oriented sources of Canadian growth.

JEL classification: O47, O51

Key words: Modern Growth Accounting, Semi-endogenous Growth Model, Economic Growth

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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). This observation suggests 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

[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).

is dictated by data availability for the empirical analysis. Canadian output 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 0.06 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 93% 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 1.3 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 99% versus 53%, 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]

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

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.

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 a constant growth path is not clear cut. To formally investigate this view, we conduct the same test as in Jones (2002). Comparing the values for the 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 2 describes the modern growth accounting framework. Section 3 presents the data and the growth accounting results. Section 4 examines the constant growth path hypothesis for Canadian and U.S. economies. Section 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 6 provides a robustness check and section 7 concludes.

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 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

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

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

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

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

$$\dot{K}_{jt} = s_{Kjt} Y_{jt} - d_j K_{jt}, \qquad K_{j0} > 0 \tag{2}$$

where s_{Kjt} is investment rate, $0 < d_j < 1$ is the depreciation rate in country j, and K_{j0} is the level of initial capital.

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

$$H_{Yjt} = h_{jt} L_{Yjt} \tag{3}$$

$$h_{jt} = e^{\psi_j \ell_{hjt}}, \quad \psi_j > 0 \tag{4}$$

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. The parameter ψ_j denotes the rate of return to schooling in country j.

New ideas creation: The process of new ideas creation is described as

$$\dot{A}_t = \delta \tilde{H}_{At}^{\lambda} A_t^{\phi}, \qquad A_0 > 0, \ 0 < \lambda \leq 1, \ \phi < 1 \tag{5}$$

$$\tilde{H}_{At} = \sum_{j=1}^{J} h_{jt}^{\theta} L_{Ajt}, \quad \theta \geq 0 \tag{6}$$

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 (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

$$L_{Ajt} + L_{Yjt} = L_{jt} = (1 - \ell_{hjt}) N_{jt} \tag{7}$$

$$N_{jt} = N_{j0} e^{nt}, \qquad N_{j0} > 0, \ n > 0 \tag{8}$$

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) 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

(3) in (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

$$y_{jt} = \left(\frac{K_{jt}}{Y_{jt}}\right)^{\frac{\alpha_j}{1-\alpha_j}} \ell_{Yjt} h_{jt} A_t^{\frac{\sigma_j}{1-\alpha_j}}, \quad \ell_{Yjt} \equiv L_{Yjt}/L_{jt} \tag{9}$$

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) to (8) exhibits a stable balanced growth path along which the growth rate of output per worker, g_{yj} is

$$g_{yj} = \gamma_j n, \quad \gamma_j \equiv \frac{\sigma_j \lambda}{(1-\alpha_j)(1-\phi)}. \tag{10}$$

Equation (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.

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 (9) forms the basis of the quantitative analysis in this paper. We first describe the data required to implement the accounting growth for Canada.

3.1 Data

Figures 2–9, show the data we use in the quantitative analysis. These data correspond to the variables in equation (9). We now describe each variable in more detail and also provide information on the parameters in (9). In order to facilitate a proper Canada–U.S. comparison, we apply the same data sources.

3.1.1 Output per hour

Output per hour is the ratio of real GDP (2011 constant prices) to average annual hours worked.[5] Figure 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 5.

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

3.1.2 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 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 higher than the that in the U.S.

3.1.3 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 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 4 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 (4) is based on the literature on 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).[6]

$$y_j = X_j\Phi_j + \psi_j S_j + u_j \tag{11}$$

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)

[6]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.

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 5 shows human capital per worker from PWT 9.0 and estimated 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.

3.1.4 Multifactor productivity

Following Jones (2002), we obtain multifactor productivity as a residual from (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 6).

3.1.5 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 7 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 6.

3.2 Growth accounting

Using (9), we can express the growth rate of output per person between *any two points*, denoted by hat (ˆ), as

$$\begin{aligned} \hat{y}_{jt} &= \frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt}) + \hat{h}_{jt} + \hat{\ell}_{Yjt} + \frac{\sigma_j}{1-\alpha_j}\hat{A}_t \qquad (12) \\ &= \frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt}) + \hat{h}_{jt} + \hat{\ell}_{Yjt} + \left(\hat{A}_{jt} - \gamma_j \tilde{n}\right) + \gamma_j \tilde{n}, \qquad (13) \end{aligned}$$

where $\hat{A}_{jt} \equiv \frac{\sigma_j}{1-\alpha_j}\hat{A}_t$. Equation (13) 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 (13) are zero along the balanced growth path. Table 1 denotes growth rates of variables which we use in constructing the decomposition shown in (13). 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.

3.2.1 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:

$$\frac{\dot{A}_t}{A_t} = \delta \left(\frac{H_{At}}{{A_t}^{\chi_j/\gamma_j}} \right)^{\lambda}, \quad \chi_j = \sigma_j/(1-\alpha_j). \tag{14}$$

Replacing $A_{jt} \equiv A_t^{\sigma_j/(1-\alpha_j)}$ in (14) yields:

$$\frac{\dot{A}_{jt}}{A_{jt}} = \delta \left(\frac{H_{At}}{{A_{jt}}^{1/\gamma_j}} \right)^{\lambda}. \tag{15}$$

By rewriting this equation in discrete format we have:

$$\frac{\Delta A_{jt+1}}{A_{jt}} = \delta \left(\frac{H_{At}}{{A_{jt}}^{1/\gamma_j}} \right)^{\lambda}. \tag{16}$$

We can also write the log-linearize form of (16) 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

$$\Delta A_{jt+1} = c + \lambda g_A (logH_{At} - \frac{1}{\gamma_j} logA_{jt}) + \varepsilon_{t+1}, \tag{17}$$

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 2 shows the estimation results using specification (17) for the log-linearized model. Estimated results encompass a range from 0.13 to 0.52 for γ_{CAN} and a range from 0.14 to 0.54 for $\gamma_{U.S.}$. 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. Alternatively, 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 which reflects sampling uncertainty, gives the range of 0.13 to 0.52 for γ_{CAN} and the range of 0.14 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, we can now do the decomposition expressed in (13).

3.3 Results

Table 3 shows 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 quite small 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 finding 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 0.10 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 0.12 percentage points (i.e. under 11% of the total average growth in output per worker). For the U.S. economy approximately 0.10 to 0.12 percentage points (i.e. under 8% of the total average growth in output per worker) is attributed to the scale effect. Excess idea growth for Canada is around 0.06 percentage points (or 5.28% of the growth in output per worker). Depending upon the values of γ_{CAN}, the share ranges from 0.05 to 0.06 percentage points while for the U.S. economy it is between 1.31 and 1.32 percentage points.

We summarize the three main points of 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 6%. By contrast, in the U.S. the shares of these two factors are approximately 19% and 73%, 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 is likely due to transitional factors rather than a new balanced growth path for the Canadian economy.

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 9, 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

$$y_{jt} = \left(\frac{K_{jt}}{Y_{jt}}\right)^{\frac{\alpha_j}{1-\alpha_j}} \ell_{Y_j t} e^{\psi_j \ell_{h_{jt}}} \nu_j \tilde{\ell}_{A,t}^{\gamma_j} \tilde{L}_t^{\gamma_j}, \tag{18}$$

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 (18) 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 $h^{\theta}_{jt} = 1$ in equation (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 (18) are growing at a constant rate. Unlike a balanced growth path, however, it does not represent a perpetual situation. We log-difference equation (18) and express the growth rate of output as

$$g_{y_{jt}} = \frac{\alpha_j}{1-\alpha_j} g_{k_{jt}} + g_{\ell_{Y_{jt}}} + \psi_j \Delta \ell_{h_{jt}} + \gamma_j g_{\tilde{\ell}_A} + \gamma_j \tilde{n}, \tag{19}$$

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 (19) hold with equality, and gives γ_{CAN}=0.057 and $\gamma_{U.S}$=0.502.

4.1 Results

Table 4 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), 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 4 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%.[7] 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 (19) holds with equality belongs to estimated econometric range for $\gamma_{U.S.}$ that we reported in Section 3.2.1. 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 3.2.1, $0.13 \leq \gamma_j \leq 0.52$). This finding confirms that the CGP hypothesis does not accurately describes the Canadian growth experiences over the last 34 years.

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 output per hour growth for Canada and the U.S. What might be the reasons behind the gap in γ_j? From (18), 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.

[7] 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.

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 (19) 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

$$\tilde{H}_{At} \;\; = \;\; \sum_{j=1}^{J} h_{jt} E_{Ajt} L_{Ajt}, \tag{20}$$

where E_{Ajt} denotes the amount of R&D spending per researcher. While (20) is a plausible generalization of (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 3.1.3. The R&D expenditure data are available since 1981 for G5 and Canada countries except U.S. Figure 8 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 8 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 7 and 8). 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 (16) and (17), ranges from a low value of about 0.14 to a high value of about 0.68 for Canadian economy. For the U.S. estimated parameter ranges from 0.14 to 0.55.[8] 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 ($h_{jt}^{\theta} = 1$).

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 0.06 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.

[8] We calculate upper limit of γ_j by imposing $\lambda = 0.04$.

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TABLE 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 2: Estimating γ_j, 1981-2014

Parameter	Specification (1)	(2)	(3)	(4)
	Canada			
λ	1.00	0.5	0.25	0.04
γ	0.1338	0.1381	0.1475	0.5157
	(0.0003)***	(0.0003)***	(0.0004)***	(0.0061)***
	U.S.			
λ	1.00	0.5	0.25	0.04
γ	0.1423	0.1468	0.1568	0.5392
	(0.0019)***	(0.0020)***	(0.0021)***	(0.0428)***

Notes: *** denotes statistical significance at the 1% level. Standard errors are in parenthesis. In specifications (1) through (3), we impose specific values of λ. We estimated lower bound of λ (λ=0.04) for U.S. and imposed the estimated value for the Canadian specification.

TABLE 3: Accounting for Canada & U.S. Growth, 1981-2014

			TRANSITION DYNAMICS				
		Output per Hour	Capital Intensity	Labour Reallocation	Human Capital	Excess Idea Growth	Steady-State Growth
λ	γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_t - \gamma_j \tilde{n}$	$\gamma_j \tilde{n}$
				Canada			
0.25	0.147	1.098	0.433	−0.016	0.519	0.051	0.111
		(100%)	(39.44%)	(−1.46%)	(47.27%)	(4.64%)	(10.11%)
0.50	**0.138**	**1.098**	**0.433**	**−0.016**	**0.519**	**0.058**	**0.104**
		(100%)	**(39.44%)**	**(−1.46%)**	**(47.27%)**	**(5.28%)**	**(9.47%)**
1.00	0.134	1.098	0.433	−0.016	0.519	0.061	0.101
		(100%)	(39.44%)	(−1.46%)	(47.27%)	(5.55%)	(9.20%)
				U.S.			
0.25	0.157	1.644	−0.088	−0.012	0.316	1.310	0.118
		(100%)	(−5.35%)	(−0.73%)	(19.22%)	(79.68%)	(7.18%)
0.50	**0.147**	**1.644**	**−0.088**	**−0.012**	**0.316**	**1.317**	**0.111**
		(100%)	**(−5.35%)**	**(−0.73%)**	**(19.22%)**	**(80.11%)**	**(6.75%)**
1.00	0.142	1.644	−0.088	−0.012	0.316	1.321	0.107
		(100%)	(−5.35%)	(−0.73%)	(19.22%)	(80.35%)	(6.51%)

Notes: This table reports the growth accounting decomposition corresponding to equation (13). The numbers in columns 3-8 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 4: 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: This table reports the growth accounting decomposition corresponding to equation (19). The numbers in columns 3-8 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.
G-6 is defined as G-5 plus Canada.

Figure 1: Canada: Average growth in real GDP per hour

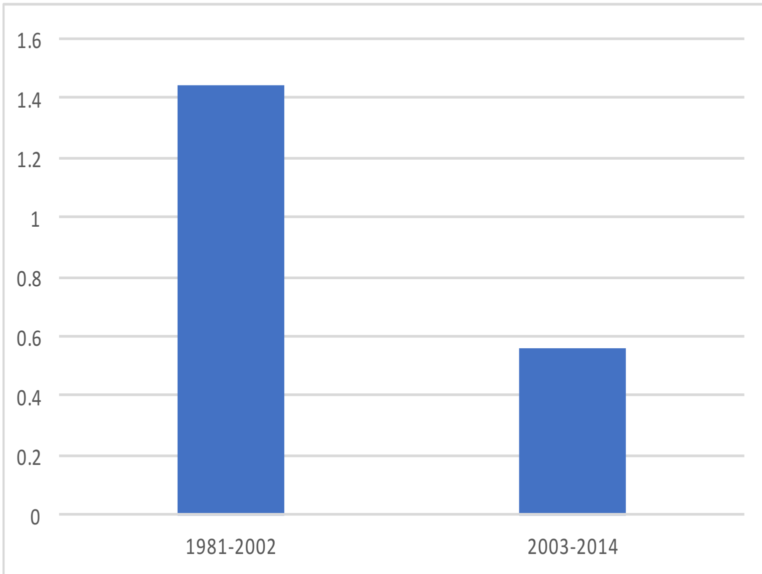


Figure 2: Canada: Real GDP per hour

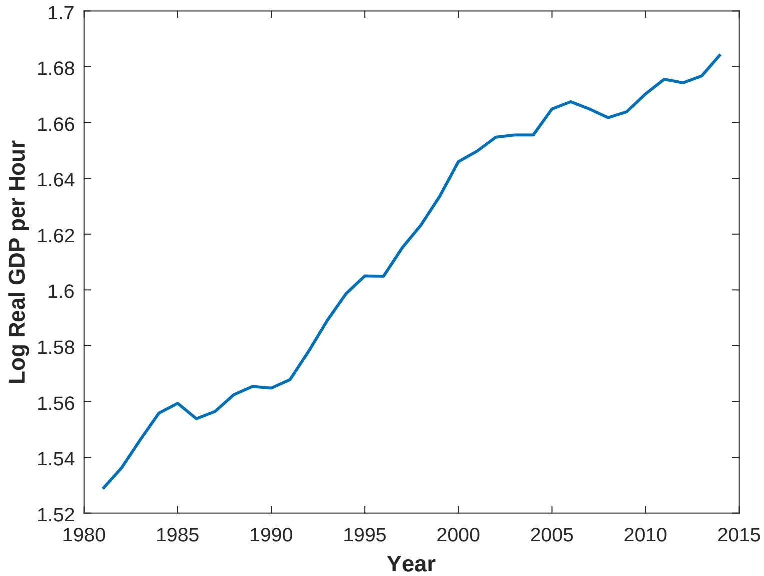


Figure 3: Capital-output ratio

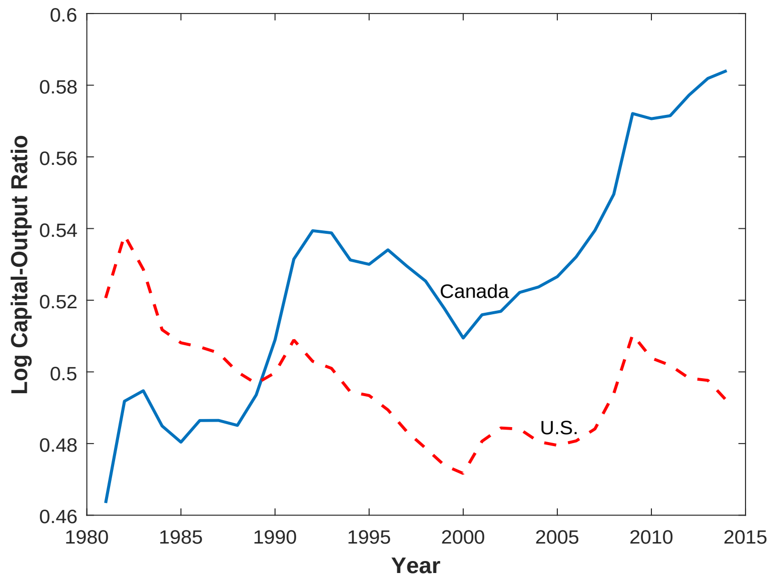


Figure 4: Average educational attainment (aged 25 and over)

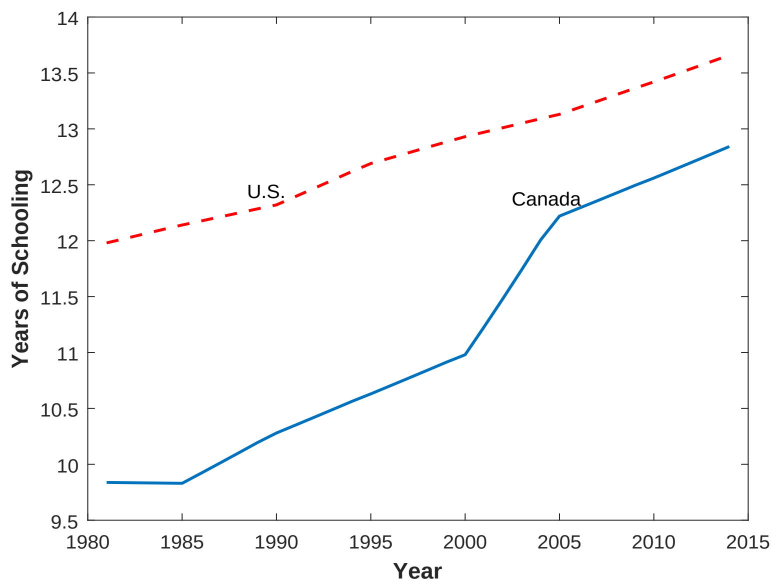


Figure 5: Human capital per worker

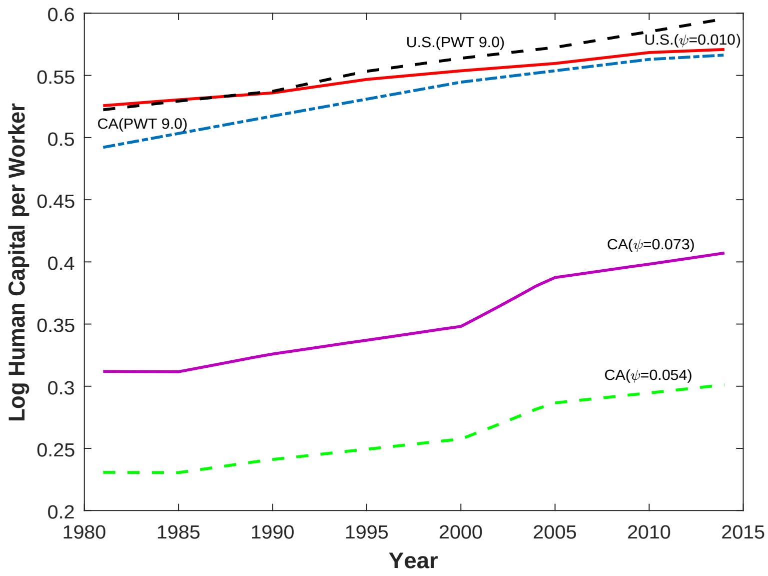


Figure 6: Multifactor productivity per hour

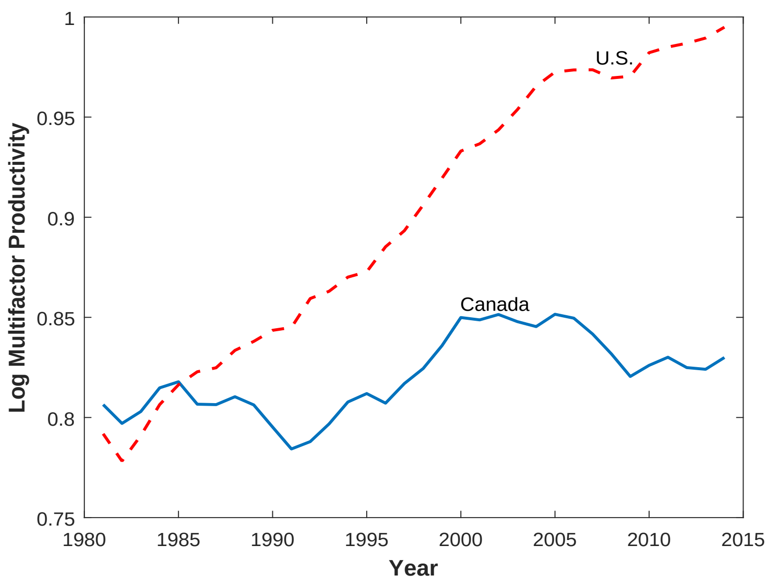


Figure 7: Country share in world research effort (baseline)

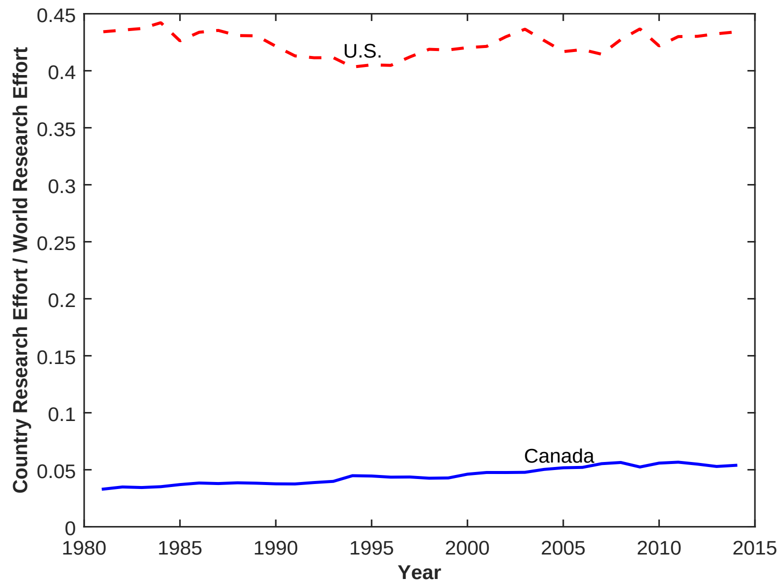


Figure 8: Country share in world research effort (robustness)

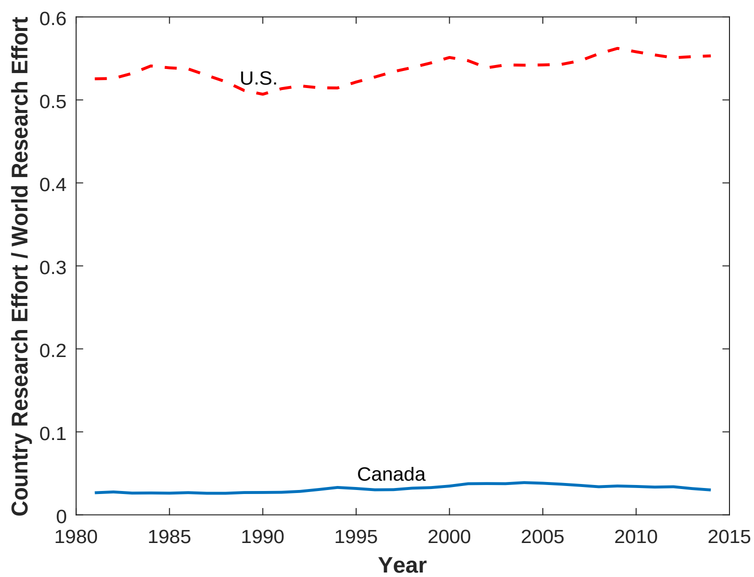
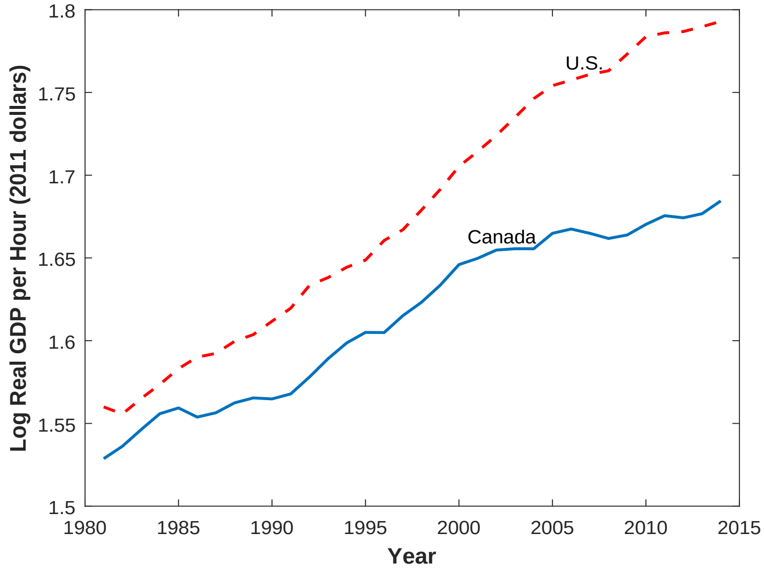


Figure 9: Real GDP per hour



8 Appendix

TABLE 5: Accounting for Canada & 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
λ	γ_j	$\hat{y}_{jt}$	$\frac{\alpha_j}{1-\alpha_j}(\hat{K}_{jt} - \hat{Y}_{jt})$	$\hat{\ell}_{Yjt}$	$\hat{h}_{jt}$	$\hat{A}_t - \gamma_j \tilde{n}$	$\gamma_j \tilde{n}$
				Canada			
0.25	0.156	1.098	0.433	−0.016	0.493	0.070	0.118
		(100%)	(39.44%)	(−1.46%)	(44.90%)	(6.37%)	(10.75%)
0.50	0.148	1.098	0.433	−0.016	0.493	0.076	0.112
		(100%)	(39.44%)	(−1.46%)	(44.90%)	(6.92%)	(10.20%)
1.00	0.142	1.098	0.433	−0.016	0.493	0.081	0.107
		(100%)	(39.44%)	(−1.46%)	(44.90%)	(7.38%)	(9.74%)
				U.S.			
0.25	0.156	1.644	−0.088	−0.012	0.512	1.114	0.118
		(100%)	(−5.35%)	(−0.73%)	(31.14%)	(67.76%)	(7.18%)
0.50	0.146	1.644	−0.088	−0.012	0.512	1.122	0.110
		(100%)	(−5.35%)	(−0.73%)	(31.14%)	(68.25%)	(6.69%)
1.00	0.142	1.644	−0.088	−0.012	0.512	1.125	0.107
		(100%)	(−5.35%)	(−0.73%)	(31.14%)	(68.43%)	(6.51%)

Notes: This table reports the growth accounting decomposition corresponding to equation (13). The numbers in columns 3-8 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour.

TABLE 6: Constant growth path decomposition: Canada versus U.S., 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: This table reports the growth accounting decomposition corresponding to equation (19). The numbers in columns 3-8 are in percentage points. The numbers in parenthesis indicate percentages of the growth rate of output per hour. G-6 is defined as G-5 plus Canada.