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Contribution of Human Capital Accumulation to Canadian Economic Growth

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Abstract

This paper quantifies the contribution of human capital accumulation to the growth of real gross domestic product (GDP) in Canada. GDP growth is decomposed into contributions from physical capital, hours worked, human capital supplied per hour and total factor productivity. Using a “flat spot” identification strategy, we separately estimate the price and quantity of human capital using wage data from the Labour Force Survey. We find that growth in human capital supplied per hour explains around one-fifth of GDP growth and two-thirds of the Solow residual over the period from 1997 to 2018. While growth in hours worked is expected to slow down in the near future, human capital supplied per hour is expected to continue to be an important driver of GDP growth.

Topics: Econometric and statistical methods; Labour markets; Potential output; Productivity
JEL codes: D24, E24, J24, J31, O47

Résumé

Dans cette étude, nous quantifions la contribution de l’accumulation du capital humain à la croissance du produit intérieur brut (PIB) réel au Canada. La croissance du PIB est décomposée en quatre éléments : le capital physique, le nombre d’heures travaillées, le capital humain fourni par heure, et la productivité totale des facteurs. En recourant à une stratégie d’identification des « plateaux », nous estimons séparément le prix du capital humain et sa quantité à partir des données sur les salaires tirées de l’Enquête sur la population active. Pour la période allant de 1997 à 2018, nous constatons que la croissance du capital humain fourni par heure explique environ un cinquième de la croissance du PIB et deux tiers du résidu de Solow. Même si on s’attend à ce que la croissance des heures travaillées ralentisse dans un avenir rapproché, le capital humain fourni par heure devrait continuer d’être un moteur important de la croissance du PIB.

Sujets : Méthodes économétriques et statistiques; Marchés du travail; Production potentielle; Productivité
Codes JEL : D24, E24, J24, J31, O47

1 Introduction

Examining what determines a country's gross domestic product (GDP) is central to understanding economic development and growth. Economists have paid particular attention to separating the roles of total factor productivity (TFP) and accumulated factors of production—physical and human capital—because they have very different implications for why GDP varies across countries and over time. A key issue for this decomposition is the measurement of human capital.

Human capital refers to any skills, competencies and knowledge workers have that potentially increase their productivity. Therefore, measuring human capital amounts to expressing the labour input in terms of efficiency units (i.e., quantity of human capital) rather than physical units (i.e., hours worked). This recognizes that the labour hours supplied by different workers may not contain the same efficiency units. The difficulty in measuring human capital arises because, unlike physical units, efficiency units are not observed directly. Even when workers are paid for their marginal product, their hourly wages reflect the amount of efficiency units supplied per hour as well as the price paid per efficiency unit. Because the price of human capital can vary across countries and over time, identifying the quantities and prices of human capital separately is challenging.

A number of different approaches to measuring human capital have been used to assess its importance for explaining differences in income between countries. These studies often lead to different conclusions, which shows the difficulty inherent in solving the identification problem. For example, Klenow and Rodríguez-Clare (1997) and Hall and Jones (1999) conclude that most of the differences in per capita income across countries are explained by variation in TFP when a country's human capital is measured based primarily on the average years of schooling in the country. In contrast, Erosa, Koreshkova, and Restuccia (2010), Manuelli and Seshadri (2014) and Hendricks and Schoellman (2017) find that TFP has a limited role because of substantial differences between countries in the quantities of human capital conditional on educational attainment.

The "flat spot" method developed by Heckman, Lochner, and Taber (1998) and Bowlus and Robinson (2012) provides a strategy for identifying changes in the quantity and price of human capital in a given country. The identification strategy is based on the theory of human capital investment over the life cycle (e.g., Ben-Porath, 1967). Just as firms invest in their physical capital to increase their productivity, individuals make various forms of investment to increase their quantity of human capital, although their incentives to invest diminish as they get older and closer to retirement. Therefore, the quantities of human capital supplied are likely to be stable for older workers, implying that their wage growth reflects growth in the price of human capital over time. In turn, estimated changes in the price of human capital over time allow for identification of changes in the quantity of human capital supplied over the life cycle and across cohorts.

In contrast to the flat spot method, typical methods to measure labour input do not fully account for the contribution of human capital to GDP growth. When labour inputs are measured simply by aggregate hours worked, as in Solow (1957), the growth in human capital supplied per hour would be included in the "Solow residual"—GDP growth that is not explained by physical capital accumulation and growth in hours worked. Composition-adjusted hours worked, developed by Denison (1962), is another measure of the labour input commonly produced by national statistical agencies (e.g., US Bureau of Labor Statistics, 1993; Gu et al., 2002). Hourly wage differentials across different groups of workers (defined by observed characteristics, including age, sex and educational attainment) reflect differences in the marginal productivity of an hour's work. As a result, growth in composition-adjusted hours worked includes higher weights on growth in hours of higher-wage groups. However, it implicitly assumes that wage growth within each group is entirely due to growth in the price of human capital. Therefore, it does not capture growth in the quantity of human capital across cohorts.

In this paper, we use the flat spot method to evaluate the contribution of human capital accumulation to GDP growth in Canada. We follow the methodology of Bowlus and Robinson (2012) and Bowlus, Robinson, and Liu (2019) to estimate the quantity of human capital of each group—based on age, sex and educational attainment—using wage data from the Labour Force Survey (LFS) available from 1997. Then we decompose GDP growth into contributions from physical capital, hours worked, human capital per hour and TFP. The growth in human capital supplied per hour is further decomposed into changes in the composition of the workforce across groups—reflecting factors such as the increasing participation of women in the labour force, increasing educational attainment and population aging—and growth in the quantity of human capital across cohorts within groups. Finally, we estimate the long-run trends of these components to predict how they will contribute to TFP in the near future.

Our findings are as follows: From 1997 to 2018, the average annual growth rate of Canadian GDP was 2.38%. Physical capital and hours worked contributed 0.97 and 0.73 percentage points (pps), respectively, to GDP growth, leaving 0.67 pps of GDP growth as the Solow residual. Around one-third of the Solow residual reflects TFP growth, and the rest is the contribution of growth in human capital supplied per hour. Around half of the growth of human capital per hour is explained by composition changes and, in particular, sustained growth in educational attainment. However, the importance of the composition change declined over time with the aging of the baby boomers (i.e., those born between 1946 and 1964). The remaining half of the growth of human capital per hour reflects growth of human capital quantity across cohorts, with strong growth for those with at least a high school education and those born after 1970.

The growth accounting framework presented in this paper can be used to improve the Bank of Canada's methodology for estimating Canada's potential GDP. Potential GDP, defined as the level of GDP that can be maintained without inflationary pressures, is a crucial input for monetary policy decisions. As described in Pichette et al. (2015), one of the models used to estimate potential GDP is the integrated framework. The integrated framework is based on the original growth accounting method of Solow (1957), where the labour input is measured by aggregate hours worked. The hours worked and Solow residual are replaced by their time trends to produce an estimate of potential GDP.

The trend in hours worked is extrapolated based on Statistics Canada's population projection to help forecast future potential GDP (Barnett, 2007).

Incorporating human capital in growth accounting can help us better interpret the Solow residual by isolating the contribution of human capital per hour. As human capital accumulation is likely to vary systematically with demographic variables, including human capital can also improve our estimation of the current and future trends of the Solow residual. To this end, we estimate the deterministic time trend of the contribution of human capital per hour to GDP growth, based on a similar methodology for estimating the trend in hours worked. According to our estimates, the contribution of human capital per hour to trend GDP growth over the next eight years is expected to be similar to the average over the period from 1997 to 2018. This suggests that while growth in hours worked is expected to slow down in the near future, human capital supplied per hour is expected to continue to be an important driver of GDP growth.

The rest of this paper is organized as follows: Section 2 introduces the growth accounting framework with human capital. Section 3 quantifies the contribution of human capital to growth. Section 4 concludes.

2 Growth accounting with human capital

In this section, we present a growth accounting framework, first proposed by Solow (1957), that has been extended to the case where multiple types of physical capital and human capital are used as inputs of production (e.g., You, 2014).

2.1 Aggregate production function

Let $Y(t)$ be real GDP at time t, which is produced by combining various types of physical and human capital. Let $K_j(t)$ be the aggregate stock of physical capital of type j supplied at time t. Similarly, let $H_i(t)$ be the aggregate stock of human capital of type i supplied at time t. Denoting the vectors of physical and human capital by $\boldsymbol{K} = (K_j)$ and $\boldsymbol{H} = (H_i)$, respectively, we can write the aggregate production function as follows:

$$Y(t) = F\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big). \tag{1}$$

For each t, the aggregate production function $F(t, \cdot)$ satisfies standard properties. It is continuously differentiable, strictly increasing and strictly concave in individual inputs of physical and human capital. Moreover, it exhibits constant returns to scale in $(\boldsymbol{K}, \boldsymbol{H})$. For future reference, let $F_t(\cdot)$, $F_j(\cdot)$ and $F_i(\cdot)$ be the partial derivatives of $F(\cdot)$ with respect to time, type j physical capital and type i human capital, respectively.

As explained in more detail in Section 3.2, we distinguish between equipment and other types of physical capital, and we define human capital types based on the educational attainment of workers. Given that different types of inputs may be differentially productive or imperfectly substitutable, we allow for multiple types of physical and human capital. For example, distinctions between equipment and other types of physical capital (Greenwood, Hercowitz, and Krusell, 1997) and between more educated and less educated workers (Katz and Murphy, 1992) are commonly made in the literature. Furthermore, the "capital-skill complementarity" hypothesis posits that equipment capital complements highly educated workers but substitutes for less educated workers (Krusell et al., 2000). These possibilities are allowed in the production function above, given our definition of types. The production function also permits general changes in the production technology over time.

As is common in the literature (e.g., Bowlus and Robinson, 2012), we assume perfect substitutability within each type of human capital. However, within each type, we allow for differences in the quantity of human capital across different groups of workers defined by sex and age. For human capital type i and group g, let $H_{i,g}(t)$ be the aggregate stock of human capital and $L_{i,g}(t)$ be the total number of hours supplied. Moreover, let $h_{i,g}(t) = H_{i,g}(t)/L_{i,g}(t)$ be the quantity of type i and group g human capital supplied per hour worked. Then the aggregate stock of human capital type i is

$$H_i(t) = \sum_g H_{i,g}(t) = \sum_g h_{i,g}(t)L_{i,g}(t). \tag{2}$$

As shown by equation (2), human capital measures the labour input in terms of efficiency units (i.e., quantity of human capital) instead of physical units (i.e., hours worked). Therefore, the growth in the quantity of human capital per hour, $h_{i,g}(t)$, appears equivalent to labour-augmenting technical progress. However, there is an important conceptual distinction between the two. While labour-augmenting technical change is "disembodied" in the sense that it affects the productivity of workers regardless of their investment levels, the growth in the quantity of human capital per hour reflects productivity gains "embodied" in workers as a result of investment.

2.2 Equilibrium factor prices

Let $\boldsymbol{R} = (R_j)$ and $\boldsymbol{P} = (P_i)$ be the vectors of rental rates of physical and human capital at time t, respectively, and normalize the price of the final good to 1. Throughout this paper, we refer to the rental rate of human capital as the "price" of human capital. Assuming that factor markets are perfectly competitive, the representative firm's profit optimization problem can be written as follows:

$$\max_{\boldsymbol{K}(t),\boldsymbol{H}(t)} \left\{ F\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big) - \sum_j R_j(t)K_j(t) - \sum_i P_i(t)H_i(t) \right\}.$$

The necessary first-order conditions for profit maximization are

$$R_j(t) = F_j\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big), \quad \forall j, \tag{3}$$

$$P_i(t) = F_i\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big), \quad \forall i. \tag{4}$$

The price of human capital equals its marginal product, which is determined by the stocks of physical and human capital as well as production technology at time t. It differs from the hourly wage—the marginal product of hours worked—because it reflects the quantity of human capital supplied per hour. Specifically, let $W_{i,g}(t)$ be the hourly wage for a worker endowed with type i human capital and in group g. It is the product of price and quantity of human capital:

$$W_{i,g}(t) = \frac{\partial F\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big)}{\partial L_{i,g}(t)} = \frac{\partial F\big(t, \boldsymbol{K}(t), \boldsymbol{H}(t)\big)}{\partial H_i(t)} \frac{\partial H_i(t)}{\partial L_{i,g}(t)} = P_i(t) h_{i,g}(t). \tag{5}$$

This illustrates the fundamental problem of identifying human capital growth: we observe only hourly wages, while the price and quantity of human capital are not observed directly. We return to this measurement issue in Section 3.1.

2.3 Growth accounting formula

Because the aggregate production function exhibits constant returns to scale and the factor markets are perfectly competitive, the equilibrium profit of the representative firm is zero, and payments to factors of production exhaust aggregate output:

$$Y(t) = \sum_j R_j(t) K_j(t) + \sum_i P_i(t) H_i(t) = \sum_j R_j(t) K_j(t) + \sum_{i,g} P_i(t) H_{i,g}(t). \tag{6}$$

Let $\alpha(t)$ be the factor income share of physical capital:

$$\alpha(t) = \frac{\sum_j R_j(t) K_j(t)}{Y(t)}.$$

Moreover, let $\beta_j(t)$ and $\gamma_{i,g}(t)$ be the factor income shares of type j physical capital and type i human capital in group g, respectively:

$$\beta_j(t) = \frac{R_j(t) K_j(t)}{\sum_{j'} R_{j'}(t) K_{j'}(t)},$$

$$\gamma_{i,g}(t) = \frac{P_i(t) H_{i,g}(t)}{\sum_{i',g'} P_{i'}(t) H_{i',g'}(t)} = \frac{W_{i,g}(t) L_{i,g}(t)}{\sum_{i',g'} W_{i',g'}(t) L_{i',g'}(t)}.$$

Notice that $W_{i,g}(t) L_{i,g}(t) = P_i(t) h_{i,g}(t) L_{i,g}(t) = P_i(t) H_{i,g}(t)$ implies that the factor income share $\gamma_{i,g}(t)$ can be computed from the earnings share of group g workers endowed with type i human capital.

Assuming time is continuous, let $\dot{x}(t) = dx(t)/dt$ be the derivative of a variable $x(t)$ with respect to time. With the definitions of factor income shares and the conditions for profit maximization, equations (3) and (4), we can decompose GDP growth into components explained by factor accumulation and an unexplained component, as follows:

$$\underbrace{\frac{\dot{Y}(t)}{Y(t)}}_{\text{GDP growth}} = \underbrace{\alpha(t)\sum_j \beta_j(t)\frac{\dot{K}_j(t)}{K_j(t)}}_{\text{Contribution of physical capital}} + \underbrace{\left[1-\alpha(t)\right]\sum_{i,g}\gamma_{i,g}(t)\frac{\dot{H}_{i,g}(t)}{H_{i,g}(t)}}_{\text{Contribution of human capital}} + \underbrace{\frac{\dot{A}(t)}{A(t)}}_{\text{TFP growth}}, \tag{7}$$

where $\dot{A}(t)/A(t) = F_t(t, \boldsymbol{K}(t), \boldsymbol{H}(t))/F(t, \boldsymbol{K}(t), \boldsymbol{H}(t))$ is TFP growth, reflecting changes in the production technology over time.

2.4 Decomposing human capital growth

Using the relationship $H_{i,g}(t) = h_{i,g}(t)L_{i,g}(t)$, the growth in aggregate human capital can be further decomposed as follows:

$$\sum_{i,g}\gamma_{i,g}(t)\frac{\dot{H}_{i,g}(t)}{H_{i,g}(t)} = \sum_{i,g}\gamma_{i,g}(t)\frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)} + \sum_{i,g}\gamma_{i,g}(t)\frac{\dot{h}_{i,g}(t)}{h_{i,g}(t)}. \tag{8}$$

Compared with the case where labour input is measured by aggregate hours worked, the two terms in equation (8) recognize additional mechanisms through which the labour input contributes to GDP growth.

Composition change. The first term in equation (8) is the growth in composition-adjusted hours (Denison, 1962). It shows how GDP growth can be affected by differential growth rates of hours worked across types of human capital or by a composition change. To see this, let $L(t) = \sum_{i,g} L_{i,g}(t)$ be aggregate hours worked, and let $\eta_{i,g}(t) = L_{i,g}(t)/L(t)$ be the share of hours worked for type i and group g. Then the growth rate of aggregate hours is

$$\frac{\dot{L}(t)}{L(t)} = \sum_{i,g}\eta_{i,g}(t)\frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)}, \tag{9}$$

and the growth in composition-adjusted hours worked can be written as the sum of growth in aggregate hours plus the composition change:

$$\underbrace{\sum_{i,g} \gamma_{i,g}(t) \frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)}}_{\substack{\text{Growth in} \\ \text{composition-adjusted hours}}} = \underbrace{\frac{\dot{L}(t)}{L(t)}}_{\text{Growth in hours}} + \underbrace{\sum_{i,g} \left[\gamma_{i,g}(t) - \eta_{i,g}(t)\right] \frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)}}_{\text{Composition change}}. \tag{10}$$

The share of earnings, $\gamma_{i,g}(t)$, is not generally equal to the share of hours worked, $\eta_{i,g}(t)$, due to differences in prices or quantities of human capital across types. A shift in hours worked toward types with a high gap between these two shares results in higher GDP growth.

Cohort effect. The second term in equation (8) reflects growth in the quantity of human capital supplied per hour across cohorts. Because we define worker groups based on age, the growth in the quantity of human capital supplied per hour over time for a given type i and group g, $\dot{h}_{i,g}(t)$, reflects cohort effects such that workers of later birth cohorts may be more productive than older cohorts were at the same age.

The cohort effects could reflect improvements in technical knowledge that are exploited by investment in new generations of workers. They could also reflect changes in the productivity of the education sector driven by shifts in public expenditures (You, 2014). Changing human capital prices over time could also generate cohort effects by affecting private human capital investment (Kong, Ravikumar, and Vandenbroucke, 2018) as well as the composition of students across educational attainment categories (Carneiro and Lee, 2011).

Growth in human capital per hour. When equations (8) and (10) are combined, the growth in aggregate human capital can be attributed to the growth in both aggregate hours worked and human capital per hour, where the latter reflects composition changes as well as cohort effects:

$$\sum_{i,g} \gamma_{i,g}(t) \frac{\dot{H}_{i,g}(t)}{H_{i,g}(t)} = \underbrace{\frac{\dot{L}(t)}{L(t)}}_{\text{Hours worked}} + \underbrace{\overbrace{\sum_{i,g} \left[\gamma_{i,g}(t) - \eta_{i,g}(t)\right] \frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)}}^{\text{Composition change}} + \overbrace{\sum_{i,g} \gamma_{i,g}(t) \frac{\dot{h}_{i,g}(t)}{h_{i,g}(t)}}^{\text{Cohort effect}}}_{\text{Human capital per hour}}. \tag{11}$$

2.5 Implications for the Solow residual

Using aggregate hours worked as the measure of labour input, the growth accounting formula of Solow (1957) decomposes GDP growth as follows:

$$\underbrace{\frac{\dot{Y}(t)}{Y(t)}}_{\text{GDP growth}} = \underbrace{\alpha(t)\sum_{j} \beta_j(t)\frac{\dot{K}_j(t)}{K_j(t)}}_{\text{Contribution of physical capital}} + \underbrace{[1-\alpha(t)]\frac{\dot{L}(t)}{L(t)}}_{\text{Contribution of hours worked}} + \underbrace{Z(t)}_{\text{Solow residual}} , \tag{12}$$

where the Solow residual is the GDP growth that is not explained by physical capital accumulation and growth in hours worked.

Equations (7) and (11) imply that the Solow residual is composed of the contribution of human capital per hour and TFP growth:

$$Z(t) = \underbrace{\overbrace{[1-\alpha(t)]\left\{\sum_{i,g}[\gamma_{i,g}(t)-\eta_{i,g}(t)]\frac{\dot{L}_{i,g}(t)}{L_{i,g}(t)}\right\}}^{\text{Contribution of composition change}} + \overbrace{[1-\alpha(t)]\sum_{i,g}\gamma_{i,g}(t)\frac{\dot{h}_{i,g}(t)}{h_{i,g}(t)}}^{\text{Contribution of cohort effect}}}_{\text{Contribution of human capital per hour}} + \underbrace{\frac{\dot{A}(t)}{A(t)}}_{\text{TFP growth}} . \tag{13}$$

Therefore, the growth accounting formula in equation (12), which does not account for changes in human capital, attributes the entire Solow residual to TFP growth, likely overestimating the importance of disembodied technical progress. Moreover, most existing growth accounting methods that take into account productivity differences between different types of workers capture only composition changes and do not take into account growth in human capital across cohorts.

3 Measuring human capital and its contribution to growth

In this section, we implement the growth accounting method according to equations (12) and (13). Because the factor income shares of each type of human capital can be inferred from the earnings shares, quantifying the contribution of composition changes does not require separate identification of prices and quantities of human capital. However, the contribution of cohort effects on human capital cannot be inferred directly from wage growth alone.

3.1 Identifying the quantities and prices of human capital

Assessing the contribution of human capital to GDP growth requires identifying prices and quantities of human capital from wage data. As can be derived from equation (5), the growth rate of wages for a type i and group g worker can be decomposed into the sum of the growth rates of the price and quantity of human capital:

$$\frac{\dot{W}_{i,g}(t)}{W_{i,g}(t)} = \frac{\dot{P}_i(t)}{P_i(t)} + \frac{\dot{h}_{i,g}(t)}{h_{i,g}(t)}, \tag{14}$$

where the growth rates of the quantity and price of human capital are not directly observable. This identification problem is often resolved by assuming that all or none of the wage growth reflects growth in the quantity of human capital. For example, growth accounting methods based only on growth in composition-adjusted hours (equation (10)) (e.g., US Bureau of Labor Statistics, 1993; Gu et al., 2002) do not incorporate the cohort effects, implicitly assuming that $\dot{h}_{i,g}(t) = 0$.

In this paper, we solve the identification problem by using the flat spot method, which was first proposed by Heckman, Lochner, and Taber (1998). Bowlus and Robinson (2012) apply the flat spot method to the United States, while Bowlus, Robinson, and Liu (2019) compare human capital prices and quantities of the United States and Canada.

According to the theory of human capital investment by Ben-Porath (1967), individuals' incentives to invest in human capital decrease toward the end of their career. Therefore, wage changes for older workers are more likely to reflect changes in prices rather than changes in quantities of human capital. Based on this idea, the flat spot method assumes that some age range exists where the quantity of human capital supplied stays constant.

To illustrate the flat spot method, assume that time is discrete, where one unit of time represents one year, and workers of type i differ only in age a. That is, let $h_{i,a}(t)$ be the quantity of human capital for workers with type i, age a in year t. Then the flat spot method assumes that there is some age range, or the flat spot, $\mathcal{A}$, such that, for all $a \in \mathcal{A}$ and all t,

$$h_{i,a}(t) = h_{i,a-1}(t-1). \tag{15}$$

In other words, for each cohort of workers born in $c = t - a$, their human capital quantity does not change over the age range $\mathcal{A}$. Because the prices of human capital for different ages are identical, we can recover price growth between years $t-1$ and t from the life-cycle wage growth between ages $a-1$ and a for cohorts who are in the flat spot. Thus,

$$\ln P_i(t) - \ln P_i(t-1) = \ln W_{i,a}(t) - \ln W_{i,a-1}(t-1). \tag{16}$$

For workers with ages outside the flat spot, their wage growth over the life cycle, along with the price growth, gives the life-cycle growth in the quantity of human capital supplied per hour:

$$\ln h_{i,a}(t) - \ln h_{i,a-1}(t-1) = \big[\ln W_{i,a}(t) - \ln W_{i,a-1}(t-1)\big] - \big[\ln P_i(t) - \ln P_i(t-1)\big]. \tag{17}$$

Moreover, we can infer the growth rate of the quantity of human capital supplied per hour at a given age a between cohorts $c-1 = t-1-a$ and $c = t-a$ from wage growth between the two cohorts:

$$\ln h_{i,a}(t) - \ln h_{i,a}(t-1) = \big[\ln W_{i,a}(t) - \ln W_{i,a}(t-1)\big] - \big[\ln P_i(t) - \ln P_i(t-1)\big]. \tag{18}$$

Equation (18) is a discrete-time approximation of equation (14).

3.2 Data source and implementation

Based on the evidence (e.g., Gordon, 1990) that there has been significant technological change in the production of new equipment (such as more powerful computers and more efficient means of communication and transportation), we distinguish two types of physical capital. The first type includes machinery and equipment as well as intellectual property products. The second type consists of non-residential buildings and engineering construction. Nominal and real values of each category of physical capital are taken from CANSIM Table 36-10-0096-01, "Flows and stocks of fixed non-residential capital," to calculate the contribution of physical capital to GDP growth.

We define types of human capital based on four education groups (high school dropout, high school graduate, some college, and university graduate) and define worker groups based on sex (male and female) and 40 single-year age groups (25, 26, . . ., 64). Therefore, there are four prices of human capital and 320 human capital quantities and hours worked to be computed in each year. Following Bowlus and Robinson (2012) and Bowlus, Robinson, and Liu (2019), we assume flat spot age ranges of 50 to 59 for university graduates, 48 to 57 for those with some college education, 46 to 55 for high school graduates and 44 to 53 for high school dropouts.

We implement the flat spot method using microdata on hourly wages and hours worked from the LFS. Because the LFS began collecting data on wages in 1997, we focus on the years 1997 to 2018. After deflating hourly wages by using the consumer price index, we estimate $W_{i,g}(t)$ by computing averages of real hourly wages for each type and group of workers in each year.[1] Then growth rates of human capital prices are calculated by averaging growth rates of wages for all cohorts in the flat spot. We use average wages of men to estimate price growth. From estimated prices, we recover human capital quantities $h_{i,g}(t)$. Finally, aggregate hours worked for each type of human capital and group of workers, $L_{i,g}(t)$, are estimated by summing weekly hours worked across all workers of the same type and group.

The growth accounting framework based on multiple types of human capital provides a historical assessment of the contribution of human capital to GDP growth. We can also use the framework to form forecasts about the future contribution of human capital to GDP growth, provided that the population structure in the near future can largely be predicted. First, for each sex and education group, we estimate additively separable cohort and age trends in log human capital quantity supplied per hour and log total hours worked per total population within age and sex groups for the years 1997 to 2018, assuming that the cohort trends are constant within the first and last five cohorts for which we have limited observations. Then we extrapolate the implied time trends into the next eight years by using the 2018 update of the national population projections (Statistics Canada, 2015) and by making a conservative assumption that the cohort trends stay constant for all future cohorts.

3.3 Growth accounting results

We conduct the growth accounting exercise for the years 1997 to 2018 based on equation (12). We first decompose GDP growth into the contribution of physical capital, the contribution of hours worked and the Solow residual. Then, based on equation (13), the Solow residual is decomposed into TFP growth and the contribution of human capital per hour, which consists of composition changes as well as cohort effects.

Table 1 shows the decomposition. The last row of Table 1 shows that, from 1997 to 2018, Canadian GDP grew 2.38% annually on average. Physical capital and hours worked contributed 0.97 pps and 0.73 pps, respectively, to GDP growth, leaving 0.67 pps of the GDP growth as the Solow residual. As shares of GDP growth, these contributions are 41%, 31% and 28%, respectively.

GDP growth was slower from 2005 to 2010, a period that includes the 2008–09 global financial crisis. The slower growth was driven by a large decline in the Solow residual and a smaller decline in the contribution of hours worked, although the contribution of physical

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[1] Bowlus and Robinson (2012) and Bowlus, Robinson, and Liu (2019) use median wages to estimate human capital prices because wages are top coded in the US data used for their analysis (March Current Population Survey). Because there is no top-coding issue in the LFS data, we use average wages for our main result. We also report some results where prices are calculated based on median wages.

Table 1: Decomposition of GDP growth

Years	GDP	Contribution of		Solow residual				
		Physical capital	Hours worked	Total	Contribution of human capital per hour			TFP
					Total	Composition	Cohort	
1997–2005	3.39	1.23	1.02	1.15	0.51	0.26	0.24	0.64
2005–2010	1.17	1.25	0.38	-0.45	0.44	0.18	0.26	-0.89
2010–2018	2.12	0.55	0.67	0.90	0.36	0.15	0.21	0.54
1997–2018	2.38	0.97	0.73	0.67	0.43	0.20	0.23	0.24

Note: The numbers are average annual growth rates (pps).

capital was robust. The Solow residual and the growth in hours worked recovered after the global financial crisis, but they are still below their pre-recession levels, which could reflect a secular decline in growth. Moreover, the contribution of physical capital declined substantially after the global financial crisis.

From 1997 to 2018, the contribution of human capital per hour to GDP growth was 0.43 pps, which is around one-fifth of GDP growth and two-thirds of the Solow residual. Around half of the growth of human capital per hour is explained by composition changes, and the other half reflects growth in the quantity of human capital across cohorts.[2] After taking into account human capital growth, the average growth rate of TFP is 0.24 pps, which is only one-third of the Solow residual. Therefore, accounting for human capital is important for measuring productivity growth.

The combined contribution of human capital per hour and hours worked, which is the contribution of aggregate human capital to GDP growth, is substantial—it explains 45% of GDP growth from 1997 to 2018. Both components play an important role, but they exhibit considerably different cyclicality and volatility. While the contribution of hours worked declined substantially between 2005 and 2010, the contribution of human capital per hour decreased only slightly. This suggests that cyclical factors may not be as important as secular factors for the growth in human capital per hour.

Bowlus, Robinson, and Liu (2019) perform a similar analysis over the years 1980 to 2000 in Canada. Assuming perfect substitutability across human capital types, they construct the

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[2] The magnitude of composition changes is comparable to the estimates of Gu and Willox (2018), who find an average annual growth rate of 0.14 pps over the period from 2010 to 2014, despite the differences in methodology. When defining worker groups, they use only seven age groups (15–17, 18–24, 25–34, 35–44, 45–54, 55-64 and 65 and older) and do not separate men and women.

aggregate quantity of human capital supplied and calculate its growth rate between 1980 and 2000 using census data. Their results imply that the contribution of human capital supplied per hour to average annual GDP growth from 1980 to 2000 was 0.56 pps, of which 0.37 pps was explained by composition changes and 0.19 pps was explained by cohort effects.[3] Comparing these with the averages over the period from 1997 to 2018 in Table 1, we can see that the contribution of human capital per hour to GDP growth declined over time (0.56 pps between 1980 and 2000 compared with 0.43 pps between 1997 and 2018). The decline was driven entirely by composition changes (0.37 pps compared with 0.20 pps), while the contribution of cohort effects increased over time (0.19 pps compared with 0.23 pps).[4]

Table 2: Decomposition of aggregate human capital growth

Worker types or groups	Total	Hours worked	Human capital per hour		
			Total	Composition	Cohort
Male	0.97	0.54	0.43	0.22	0.21
Female	0.97	0.68	0.29	0.11	0.18
No college	-0.09	-0.24	0.15	0.10	0.05
At least some college	2.03	1.46	0.57	0.23	0.34
Ages 25–44	0.60	0.15	0.45	0.16	0.30
Ages 45–64	1.34	1.07	0.27	0.18	0.09

Note: The numbers are average annual growth rates (pps).

Based on equation (11), Table 2 shows the contributions of various population subgroups to the growth of aggregate human capital. From 1997 to 2018, male and female workers contributed equally to the growth of aggregate human capital. However, most of the contribution of women reflects increasing hours worked rather than growth in human capital per hour.[5] Increasing educational attainment during this period shifted the growth in hours worked toward more educated workers, and their human capital per hour worked also grew

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[3] Between 1980 and 2000, aggregate human capital, composition-adjusted aggregate hours worked and aggregate hours worked increased by 66%, 56% and 40%, respectively. Assuming a constant labour share of two-thirds, these cumulative growth rates imply contributions to average annual GDP growth of 1.63 pps, 1.44 pps and 1.07 pps, respectively. Taking differences gives the contributions of composition changes and cohort effects of 0.37 pps (= 1.44 − 1.07) and 0.19 pps (= 1.63 − 1.44).

[4] It should be noted that Bowlus, Robinson, and Liu (2019) estimated human capital prices using median wages (rather than average wages), which could affect the contribution of the cohort effect. As shown in Table A-1 in the Appendix, the contribution of the cohort effect to GDP growth from 1997 to 2018 doubles (from 0.23 pps to 0.49 pps) when median wages are used to estimate human capital prices.

[5] This contrasts with the earlier period from 1980 to 2000, when women contributed more than men in both hours worked and human capital per hour (Bowlus, Robinson, and Liu, 2019).

faster compared with that of less educated workers. The growth in hours worked is concentrated among older workers due to population aging, while younger workers experienced faster growth in human capital per hour. The strong growth in human capital per hour for more educated and younger workers primarily reflects cohort effects rather than composition changes within those subpopulation groups.

3.4 Trends in composition change

Next, we describe the forces behind the growth in human capital per hour through composition changes. As illustrated by equation (10), a composition change occurs when there is a shift in the share of hours worked across worker types and groups, and its effect is positive if growth of hours is concentrated among higher-wage workers. The changing composition of Canadian workers is summarized in Chart 1, which presents the shares of hours worked by different groups of workers defined by age, sex and educational attainment (dotted lines), along with their estimated trends (solid lines) extrapolated through 2026.[6]

Between 1997 and 2018, the share of hours worked by women and university graduates increased by 4 pps and 13 pps, respectively. The rising rates of female labour force participation and increasing educational attainment are expected to continue in the near future as older cohorts are replaced by younger cohorts. Another important change in the composition of the workforce arises from population aging. As the baby boomers (who were 36 to 54 years old in 2000) aged, the share of hours worked by those aged 55 to 64 increased over time. However, the trend of the workforce aging is expected to slow down, or even reverse slightly, once all the baby boomers have retired from the workforce. In particular, the share of hours for workers aged 55 to 64 is likely to decrease after 2020, while the share of hours for those aged 35 to 44 is expected to increase as the children of the baby boomers age.

We can assess the magnitude of the composition changes due to population aging, increasing female labour force participation and increasing educational attainment by constructing counterfactual trends that assume that each of these changes did not occur. For example, the counterfactual trend without population aging can be calculated by holding constant at its initial 1997 level the distribution of hours over age within each group defined by sex and education. Chart 2 reports the estimated trend of composition changes—that is, the second term of equation (10)—as well as the counterfactual trends.

The black line shows that the effect of composition changes is positive, but the effect declines steeply until 2010 and is relatively stable afterward. Most of the decline reflects the

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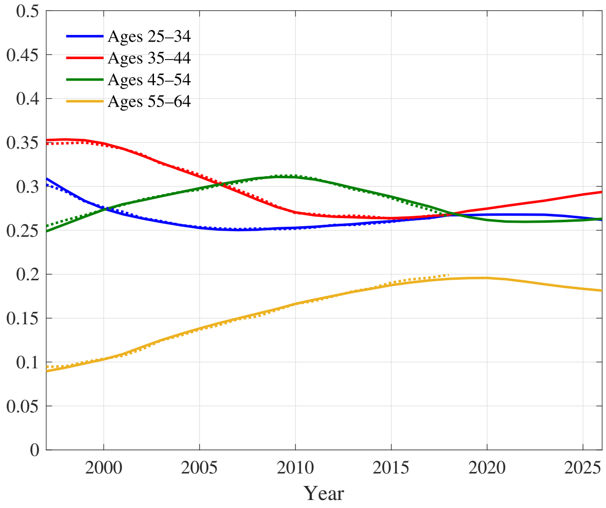
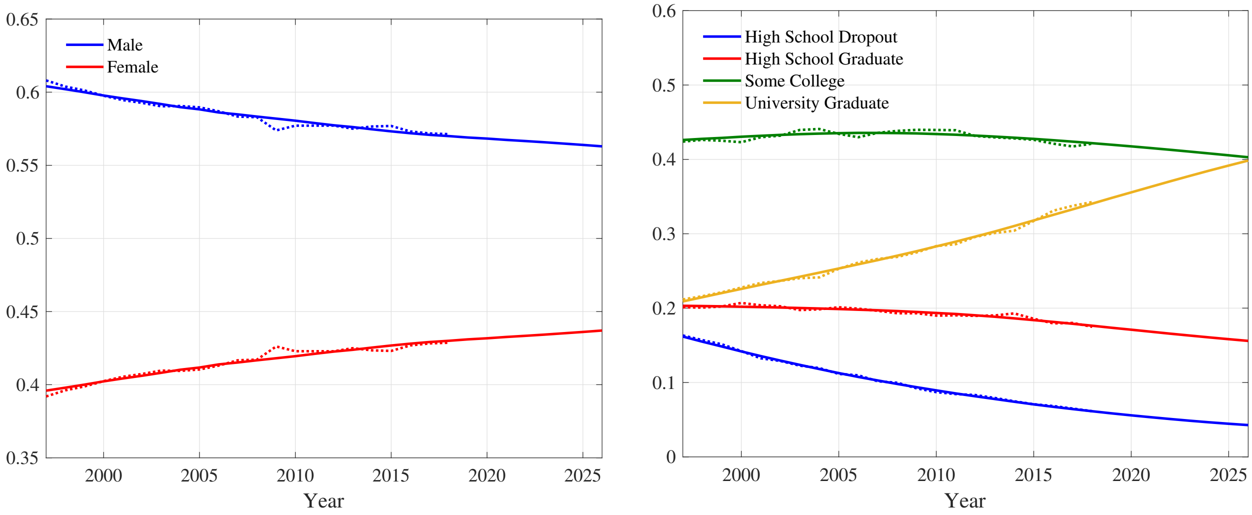
[6] It should be noted that this analysis does not take into account the effect of the COVID-19 pandemic.

Chart 1: Share of hours worked by population subgroup



(a) Age

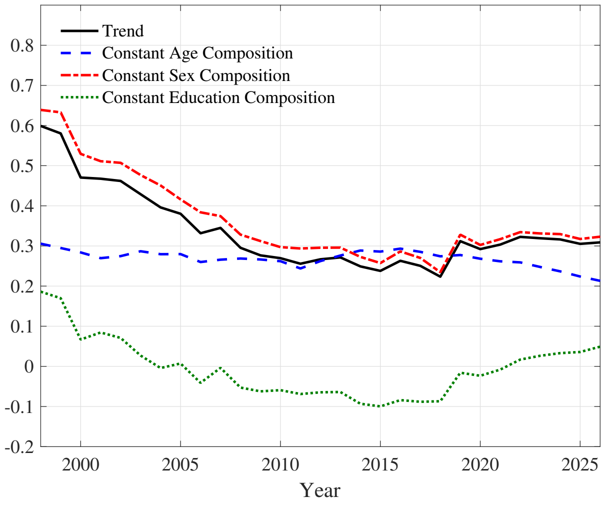


(b) Sex

(c) Education

Note: Dotted lines represent actual shares up to 2018, and solid lines represent estimated trends that are projected through 2026.

Chart 2: Trend composition changes and counterfactual trends (pps)



aging of the baby boomers. Without population aging, it would have been stable until 2020 and would be expected to decrease after 2020 (blue line). Because older workers earn higher wages than younger workers, the aging of the young baby boomers led to positive composition changes, although this effect diminished over time as many baby boomers reached middle age. Similarly, the aging of the baby boomers' children in the near future (represented by the rise in the share of hours by those aged 35 to 44) is expected to lead to greater composition changes. This can be seen from the widening gap between the trend (black line) and the counterfactual trend with constant age distribution (blue line) of composition change after 2020.

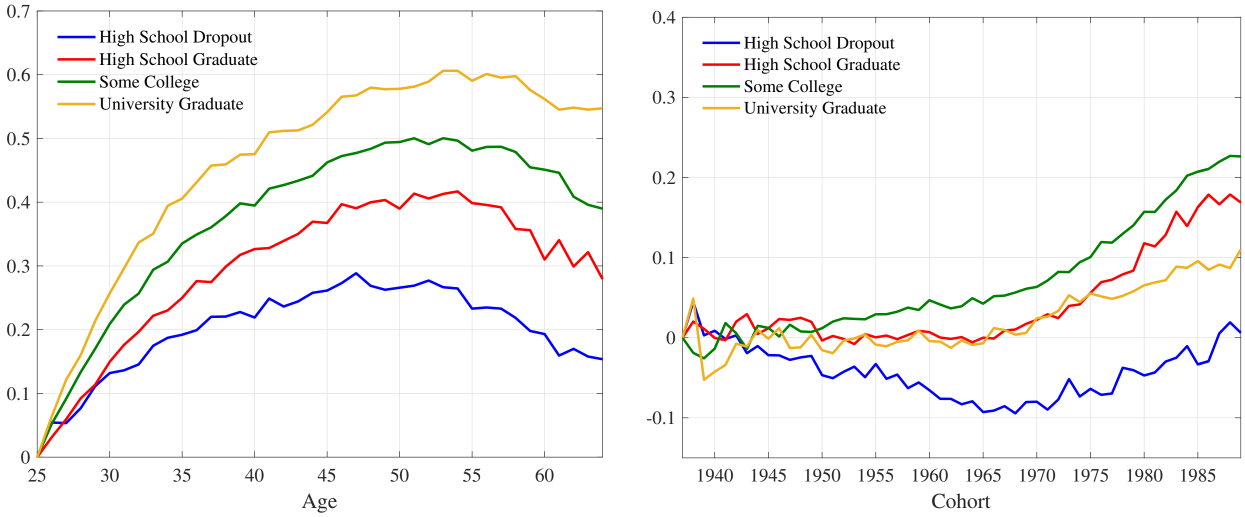
In contrast, the level of composition change is driven mostly by increasing educational attainment. The green line shows that, with a constant education composition across the workforce, the trend composition change would be around 0.3 pps lower. Because workers with more education earn higher wages, the sustained rise in the share of hours worked by more educated workers leads to positive composition effects.

Finally, the red line shows that the growing share of hours worked by women is a negative composition change because women generally earn less than men. However, its magnitude is relatively small because the change in women's share of hours has been only modest since 1997.

3.5 Trends in cohort effect

As explained in Section 2.4, the quantity of human capital supplied per hour could differ across cohorts for various reasons. We estimate the cohort trend of log human capital supplied per hour by assuming that it is additively separable from the age trend.[7] Chart 3 shows the estimated trends by age and cohort for men.

Chart 3: Trends of log human capital quantity supplied per hour, males



(a) Age trends (relative to age 25)

(b) Cohort trends (relative to 1937 cohort)

The estimated age trends show that more educated workers experience higher growth in the quantity of human capital over the life cycle. The trends are hump-shaped for all education groups, consistent with the theory of Ben-Porath (1967). The locations of the humps reflect the assumed flat spot ranges.

The estimated cohort trends show that the quantity of human capital supplied per hour grew substantially for all education groups except high school dropouts, for whom the quantity actually declined from the 1940 cohort to the 1965 cohort.[8] The growth across cohorts was stronger for middle-education groups—high school graduates and those with some college education—than for university graduates.

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[7] Although the additive separability is a strong assumption, it allows us to summarize the trends across cohorts in a parsimonious way.

[8] The estimated cohort trends should be interpreted with caution. As noted in Section 3.3, the cohort effects tend to be underestimated when human capital prices are estimated based on average wages rather than median wages. Based on the price series estimated using median wages, Bowlus, Robinson, and Liu (2019) find considerable growth from the 1946 cohort to the 1961 cohort for university graduates. Moreover, when estimating the cohort trends, they looked only at the 30 to 45 age range.

Given the sustained growth in the quantity of human capital supplied per hour across more than 20 cohorts, our assumption that the cohort effects are constant for all future cohorts is likely to be a conservative one.

3.6 Implications for future GDP growth

The contributions of these trends to past and future GDP growth through growth in human capital per hour are presented in Table 3. First, the contribution of the composition change declined from 1997 to 2018 due to the aging of the baby boomers. However, this trend is expected to reverse slightly from 2018 to 2026 as retiring baby boomers are replaced in the labour force by their children's generation. Second, the contribution of cohort effects increased over time. Further, over the period from 2018 to 2026, its level is expected to be similar to that of the period from 2010 to 2018, despite our conservative assumption about future cohorts.[9]

Table 3: Contribution of human capital to trend GDP growth

	Years	Hours worked	Human capital per hour			Total
			Total	Composition	Cohort	
Historical	1997–2005	0.88	0.47	0.29	0.18	1.34
	2005–2010	0.66	0.41	0.18	0.23	1.07
	2010–2018	0.45	0.42	0.15	0.27	0.86
	1997–2018	0.66	0.44	0.21	0.22	1.10
Projected	2018–2026	0.38	0.45	0.19	0.26	0.83

Note: The numbers are average annual growth rates in percentage points.

As a result, the quantity of human capital per hour is expected to contribute 0.45 pps to trend GDP growth from 2018 to 2026. That is a slightly larger contribution compared with the average from 2010 to 2018 and similar to the average from 1997 to 2018. The continuing growth in the quantity of human capital per hour partially offsets the declining contribution of hours worked that is due to slower population growth. Over the period from 2018 to 2026, hours worked is expected to contribute 0.38 pps to trend GDP, which is a contribution that is 0.07 pps smaller than the average from 2010 to 2018. Once growth in human capital per

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[9] Table A-1 in the Appendix shows that the contribution of cohort effects from 2018 to 2026 is even stronger when human capital prices are estimated based on median wages.

hour is taken into account, however, the contribution of aggregate human capital from 2018 to 2026 is expected to be only 0.03 pps smaller than the average from 2010 to 2018.

4 Conclusion

In this paper, we use the methodology developed by Bowlus and Robinson (2012) to assess how much the quantity of human capital supplied per hour contributes to the growth of Canadian GDP. We find that both composition changes and cohort effects have played an important role in the past and that these trends are expected to continue into the future.

Our analysis suggests that taking human capital into account reduces the importance of disembodied technical progress for GDP growth. However, our historical decomposition based on growth accounting does not reveal what causes the growth in human capital. Further work is required to determine the fundamental cause that led to human capital accumulation in Canada.

Appendix

Table A-1: Contribution of human capital per hour to GDP growth: Prices based on median wages

	Years	Actual			Trend		
		Total	Composition	Cohort	Total	Composition	Cohort
Historical	1997–2005	0.68	0.26	0.41	0.64	0.29	0.35
	2005–2010	0.74	0.18	0.56	0.58	0.18	0.40
	2010–2018	0.44	0.15	0.29	0.58	0.15	0.43
	1997–2018	0.60	0.20	0.40	0.60	0.21	0.39
Projected	2018–2026				0.58	0.19	0.39

Note: The numbers are average annual growth rates in percentage points.

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