Different Paths? Human Capital Prices, Wages and Inequality in Canada and the US (Preliminary and Incomplete Draft: Please do not quote) *

Audra J. Bowlus
University of Western Ontario[†]

Chris Robinson
University of Western Ontario [‡]

Haoming Liu
National University of Singapore [§]

October 26, 2016

Abstract

In the last three decades, Canada and the US showed different paths in per capita GDP growth, skill premiums and inequality. Human capital prices and quantities are estimated using the methods developed in Bowlus and Robinson (2012) to examine their separate roles in these differences. In the US there was faster growth and a much more rapid rise in skill premia and inequality. This was primarily due to different paths for the relative price paid to rent high skilled human capital in the two countries, rather than differences in relative quantities of human capital supplied by the typical high skilled worker. The divergent paths across countries for the two countries are interpreted within the framework of the canonical model.

*This work was supported by the Centre for Human Capital and Productivity at the University of Western Ontario and the Canadian Social Sciences and Humanities Research Council.

[†]Department of Economics, University of Western Ontario, London, ON N6A 5C2, Canada, e-mail: abowlus@uwo.ca.

[‡]Department of Economics, University of Western Ontario, London, ON N6A 5C2, Canada, e-mail: robinson@uwo.ca.

[§]Department of Economics, National University of Singapore, 1 Arts Link, Singapore 117570 e-mail: ecsliuhm@nus.edu.sg.

1 Introduction

In the last three decades, Canada and the US showed different paths of standard of living growth, skill premiums, and inequality.[1] In this paper we use estimates of human capital prices and quantities for the two countries in order to examine their separate roles in explaining these different cross country paths within the framework of the canonical model of wages and employment. The canonical model has been developed by the literature to explain the path of the college or skill premium over the last three or four decades in the US.[2] In this simple supply and demand model model there are three components: (1) relative demand for high skill, incorporating skill biased technological change (SBTC) parameters, (2) relative supply of high skill, and (3) an elasticity of substitution between high and low skill. Within this model framework, cross country differences in the path of the skill premium can be examined in terms of differences in these three basic components.

Potential sources of cross country differences in SBTC are different industrial structures, different environments for firms regarding taxes, R & D incentives, etc. Differences in relative skill supplies can arise from different education policies, or more generally different environments for investing in human capital leading to different human capital choices. An additional important source of supply differences is the very different immigration policies of the two countries. Under Canada's points system Aydemir and Borjas (2007) estimate that immigration in the 1980-2000 period resulted in a large positive "shock" to the relative supply of high skilled workers, while low skilled immigration into the US resulted in a substantial negative "shock" to the relative supply of high skilled workers in that country.

The canonical model is a supply and demand model of skill prices and skill quantities for two skill "types", high and low. It is usually implemented using measures of wages and total hours of the two skill types that are adjusted for the composition of the labor force within the two types as the proxies for true skill prices and quantities. However, there is increasing evidence that important cohort effects over the last three or four decades caused the simple composition adjusted wages and hours to be relative poor proxies for the true skill prices and quantities over this period. Bowlus

[1] The *Centre for the Study of Living Standards* using a variety of measures documents a marked decline in relative standard of living for Canada between 1980 and the mid 1990s; for example, using GDP per capita, Canada's level fell from over 90% relative to the US in 1981 to 80% in 1996. (The data are available in Chart 1 and Table 3 at http://www.csls.ca/data/ict.asp.)

[2] This framework, used most notably in Katz and Murphy (1992), Card and Lemieux (2002) and Autor Katz and Kearney (2008) was termed the "canonical model" by Acemoglu and Autor (2011)

et al. (2016) show that use of these proxies results in estimates of the three components of the canonical model for the US that are quite different from those taking into account cohort effects. In this paper we estimate skill prices and quantities for the two countries based on the methods of Bowlus and Robinson (2012), hereafter BR, that account for the cohort effects.

Under a competitive market assumption, as in the canonical model of wages and employment, the wages of a worker of a given type in either country is given by the product of the price for that skill type and the amount supplied by the worker of that skill type. Differences in the path of the standard of living as it relates to real wages for high or low skilled workers, therefore, can be due to differences in the path of the high or low skill prices and/or differences in high or low skill quantities supplied by a high or low skilled worker. The paper examines the contribution of these separate components to Canada-US differences.

At the aggregate level, assessing the contribution of human capital to output, living standards and growth has been studied extensively in the past literature. However, there remain serious conceptual and measurement problems, especially for international comparisons and for secular analyses over several decades. Since human capital is not directly measurable, a variety of approaches to measurement have been taken in the literature. Most of these are based on what in the original human capital models are more appropriately interpreted as inputs into the human capital production function rather than the output, such as years of schooling. A refinement of this takes into account work experience - usually in the form of some measure of total accumulated time at work and some demographic characteristics. For international comparisons, in the absence of measures at a more detailed level, a common procedure is to compare the fraction of the relevant populations with various levels of education.[3] However, for a variety of important contexts, it is widely recognized that a better measure of human capital is needed.[4]

[3]For example, the OECD report comparisons of a such a measure, designated A1, which the publication characterizes as "traditionally used to proxy the stock of human capital" *Education at a Glance - OECD Indicators*, OECD 1998, p. 7. However, this can result in misleading conclusions. According to the latter measure, Canada has higher per capita human capital than the United States. However, the US has a higher fraction of the population with a university degree. If this measure was used instead of the fraction with post-secondary education the ranking would be reversed.

[4]The issue of internationally comparable human capital measures that takes into account quality variation across country has received a great deal of attention. Barro and Lee (1993, 1996), for example, constructed measures of schooling years, designed to be internationally comparable, but stressed that the measure of years did not take into account quality differences. Hanushek and Kim (1995) and Hanushek and Kimko (2000) use international test score data to address the issue of schooling and labor force quality. Coulombe, Tremblay and Marchand (2004) utilize data from the International Adult Literacy Survey, and argue that human capital measures based on these data are superior to years of schooling measures normally used in international growth regressions. However, this literature pays little attention to the issue of quality variation over time within countries, or to the identification or interpretation problems

The standard approach to measurement of human capital in the canonical model framework is based on labor force composition adjustment. Total skill supplies are computed as composition adjusted quantities for two skills using education, experience and sex as the relevant composition cells. For comparative analysis for the three countries, Canada, the UK and the US, the same method may be applied separately for the three countries, as in Card and Lemieux (2001). Our alternative approach to measuring human capital is based on the methods of BR. Using the methods of BR total skill supplies are calculated by dividing the (observed) total payment for a skill by an estimated skill price based on an optimal life-cycle investment human capital model. For cross country comparison this requires estimated skill price series for the two countries. In either case, however, as argued in Section 2 below, there remains a major identification problem for a comparative analysis of cross country differences in levels. The analysis in this paper is therefore confined to a comparison of changes (paths) rather than levels.

The structure of the paper is as follows. Section 2 describes the data sources and presents estimates of the price series, based on BR, for the two countries. A major difference in the relative price paths is a much larger drop in the university price relative to the price for lower skilled workers in Canada compared to the US. The reason for this difference is discussed within the framework of the canonical model. Section 3 briefly describes the canonical model framework and nests the alternative forms of implementation, either using standard composition adjusted measures or price and quantity series based on BR. The discussion follows Bowlus *et al.* (2016). There are two important results noted in this section. First, the cohort effects emphasized in BR, Carneiro and Lee (2011) and Hendricks and Schoellman (2014) appear in the basic canonical model in exactly the same way as SBTC. Second, the cohort effects appear in the extended canonical model with imperfect substitutability across age within skill as age specific SBTC effects. Incorporating the cohort effects is therefore likely to affect the estimated cross country differences in SBTC and the elasticity of substitution.

The canonical model gives us the sources, if not a full explanation, of the cross country price path differences, and hence the source of the part of the relative wage path differences due to prices. That leaves the relative wage path differences due to differences in the path of per worker (hour) efficiency units of human capital within skill or education group. An important part of the increased inequality in the US is the large increase in the university wage premium, primarily for young

that occur if human capital is heterogeneous.

university graduates, that occurred from the late 1970s to the mid 1990s. The college premium in the US generally refers to the wage difference between workers with a BA degree or higher to the wages of a high school graduate. For this paper, comparing the US and Canada, we use "university" to refer to a BA degree or higher, and substitute "university premium" for "college premium". BR show that, while there was some relative price increase, a large part of the increased university premium in the US was due to increased per worker efficiency units for young university graduates relative to high school graduates. Section 4 compares the path of the university premium in the two countries and shows that the much smaller increase in the premium for Canada is primarily due to the difference in the price path. There was an increase in per worker efficiency units for young university graduates relative to high school graduates in both countries, but this translated into a larger wage premium increase for the US because of a larger relative price increase.

Section 4 shows increases in per worker efficiency units for young university graduates relative to high school graduates in both countries played major roles in determining the increases in the university premiums. The path of per worker efficiency units of human capital within skill or education group is determined by the human capital investment profiles of the various cohorts of workers in the two countries. Section 5 examines cohort effects in the two countries as they are reflected in the life-cycle human capital profiles of young Canadian and US university cohorts. Life-cycle human capital profiles by birth cohort are estimated, and the cross country differences are interpreted for both countries within the framework of BR.

Section 6 compares the paths of wages and per worker efficiency units supplied across countries for different age and education groups separately. The role of the different price paths in is examined. Canadian university graduates did worse in terms of wages relative to US university graduates. This was not because the amount of human capital of the typical Canadian university graduate deteriorated markedly relative to the average US university graduate, but rather because the (high) skill price in Canada fell relative to the price in the US. Another notable feature is the difference for the lower education groups, especially older dropouts, that do much better in Canada.

Section 7 examines the implications of the estimated human capital paths for multi-factor productivity (MFP) growth in the two countries. The high correlation in the BR price series for the different types of labor in the US suggest that, for the purposes of aggregate productivity analysis, a homogeneous human capital model may be a useful approximation. The estimated price series in Section 3 suggest that the same may be true for Canada. In BR, using a homogeneous human capital model with a single price series to obtain estimates of the true aggregate labor input, the role of MFP growth in the growth of output in the US was reduced to a negligible role. In Section 7, the analysis is repeated for Canada and a comparison made. The results show that as for the US, standard composition adjusted hours methods under count the increase in the aggregate labor input and hence result in an over-estimate of the growth in MFP. The results for Canada are qualitatively the same as for the US, though the extent of the under count of the aggregate labor input is smaller. As a result the gap in MFP growth between the two countries is reduced. Section 8 concludes.

2 Skill Prices for Canada and the US

Price series for four types of human capital, defined by education group, are estimated for Canada and the US and the paths of the price series are compared.

2.1 Identification of Prices Within Countries

In standard human capital models a worker's hourly wage in period t is the product of a price and a quantity

$$w_{t,i} = \lambda_t E_{t,i}, \tag{1}$$

where $E_{t,i}$ is human capital (number of efficiency units) supplied by individual i to the firm in period t and λ_t is the rental rate (the price of an efficiency unit). In a homogeneous human capital model there is a single price, λ_t. In heterogeneous models an efficiency units approach is retained within an exogenously defined worker type (e.g. college graduate type) but is abandoned across types, yielding multiple types of human capital and multiple prices. Since the hourly wage is observed, but the separate price and quantity components of interest are not, there is an identification problem. Standard implementation of the canonical model implicitly solves the identification problem by assuming that the per worker hour quantities of human capital associated with any observed education-age-gender cell are the same over time, that the cells can be assigned to two human capital types based on observed education, and that efficiency units hold within each human capital type. This permits the identification of changes in the skill price ratio from changes in the (cell) composition adjusted wage ratio.[5]

[5] The fixed relationship between the quantities of efficiency units for each cell within a human capital type is estimated by the relationship between the cell wages within type, averaged over the whole period, and these are then used as weights to weight the cell hours.

However, constancy of the per worker hour cell quantities is a very strong assumption for an analysis covering several decades. It assumes no selection effects on average quantities of human capital supplied by education group even though there have been large increases in the fraction of successive birth cohorts choosing higher levels of education. It rules out within cell per worker hour human capital increases that might be expected for females in cohorts with greater life-cycle labor force attachment.[6] It also rules out technological change in human capital production functions. Since major quality improvements due to technological change have been found for capital inputs such as computers, it is surprising that they have not been considered for the labor input. BR argue that technological improvement in human capital production functions produces workers of a given observed type, such as college graduates, that can do more, in the same sense as more recent computers can do more, especially at higher levels as knowledge advances.[7] There is, in fact, increasing evidence that the constant cell quantities assumption behind the composition adjustment approach is a poor one for an analysis covering the last three or four decades during which there were large cohort changes in education level and female participation, as well as potentially significant changes in human capital production functions.[8]

In BR a method for identifying prices and quantities without the assumption of constant per worker hour cell quantities is developed and implemented on U.S. data. The framework uses a fixed number of "types" of human capital, indicated by education group, as in the composition adjustment approach, but allows quantities within type to change over time. This introduces cohort or vintage effects, but represents a parsimonious specification of vintage effects since it maintains a constant number of human capital types and prices. BR use a "flat spot" approach to identification. In their framework, the optimal human capital investment path for each human capital type has a range towards the end of the working life where efficiency units are constant. This offers a strategy for identification. Under the assumption of competitive markets for human capital, given two periods in which a worker's efficiency units are equal (a "flat spot"), the change in log prices across periods is given by the change in log wages.[9] Thus, given two samples of individuals in their flat spots

[6]See Bowlus and Robinson (2016) for estimates of strong cohort effects for females over the period of changing participation.

[7]See BR for further discussion of the vintage issue. BR assume technological progress for the college graduate production function, embodying the advancement of knowledge. However, for lower education groups technology changes could be positive or negative. See Green and Riddell (2013), and Barrett and Riddell (2016) for evidence on this.

[8]See Carneiro and Lee (2011), Hendricks and Schoellman (2014), Bowlus and Robinson (2016).

[9]A "flat spot" approach to identification based on human capital theory was first proposed in Heckman, Lochner

for which the mean log (supplied) efficiency units are equal across periods, the change in log prices across periods can be estimated by the change in mean log wages:

$$Mean[lnE_{t,i}] = Mean[lnE_{t+1,i}] \Rightarrow Mean[lnw_{t+1,i}] - Mean[lnw_{t,i}] = ln\lambda_{t+1} - ln\lambda_t. \quad (2)$$

2.2 Identification for Cross Country Comparison

Given a normalization on the BR price series by skill type for the US, this implies corresponding quantity series for human capital, given the wage series. This allows the identification of changes in quantities within type across time or across cohorts. The same methodology of BR is used to construct equivalent price series for Canada. A normalization of the Canadian price series, implies normalized quantity series for Canada, and allows the identification of changes in these normalized quantities within type across time or across cohorts for Canada. However, this identification, unfortunately, does not extend to cross country comparisons in the quantities or prices, due to the same fundamental identification problem in human capital models. We may observe, for example, the wage of a university graduate of the same age in both countries, but we do not observe the separate price and quantity components.

The identification strategy embodied in Equation (2) is based on finding samples where the quantities are the same so the relative prices can be inferred from the relative wages. One possibility for cross country comparisons would be to follow migrants across the two countries at an age when the migrants were in their flat spot region. However, this is likely to involve very small samples (migrants tend to be young) and, more importantly, there is a large body of evidence documenting the fact that migrants are highly selected. Thus, international comparisons of levels continue to face formidable measurement challenges. This same problem occurs for composition adjustment methods where the ratio between the per worker hour quantities in each country for at least one cell is required for a comparison of levels. However, it is possible to make cross country comparisons of changes over time. For example, using the BR approach it is possible to ask: do the relative wage patterns for university graduates in the two countries imply that the quality of US university graduates (per capita quantity of efficiency units) increased at a faster pace than those of Canada, or that they simply experienced a more rapid rise in the price. Thus, many interesting questions relating to the relative paths of standard of living, of inequality and the college premium, and of the aggregate labor input and productivity can be addressed without direct comparability of the levels.

and Taber (1998).

2.3 Data Sources

The data source for the price series for the US is the annual March series from the Current Population Survey (MCPS). The MCPS records annual labor incomes for the year preceding the survey. In BR, data from the March files for 1964 to 2009 were used to construct the price series for earnings years 1963 to 2008 for four types of human capital defined by their education group: high school dropouts, high school graduates, some college and university graduates. In this paper the price series is extended to 2014. Two main issues for obtaining a consistent series from the MCPS are a break in the education group definitions in 1991 and time varying top-coding and allocation methods. The education break in the MCPS at the level of the four education groups is studied Jaeger (1992) using data over a period of overlap in the definitions and he provides evidence useful for constructing consistent series. How issues of consistency over time for education and earnings are dealt with are discussed in detail in BR.

Construction of the price series for Canada is more complicated and cannot be done for the same extended period. In order to construct price series using the flat spot method it is necessary to observe earnings for a cohort over reasonably adjacent time periods. In addition, it is necessary that the education groups are defined in a consistent way across the adjacent time periods. Finally, relatively large sample sizes are required for the data set to provide reasonable sample sizes in the flat spot regions for each of the education groups. In this paper price series for Canada are constructed using two large data sets for two periods in which the definition of the education groups is consistent within period, and for which an earnings measure is available. The first is the Canadian Census data for the earnings years 1980, 1985, 1990, 1995 and 2000. The second is the pooled monthly Labour Force Surveys (LFS) for 1997-2015.

The switch from the Canadian Census to the LFS after 2000 is primarily because of a major break in the education groups between the 2000 and 2005 and the dropping of the census long form after 2005 which introduced major comparability issues for 2010 earnings year data from the Census. The LFS has the additional benefit of allowing the construction of an annual price series to compare with the US annual price series from the MCPS. The census data for Canada come from the Statistics Canada Research Data Centre (RDC) confidential census files for 1981, 1986, 1991, 1996, 2001 and 2006. Canada has held a census every five years since 1971. In all years except 1976 the census contains measures of total wage and salary earnings and total weeks worked in the previous year, as in the MCPS for the US. There is no measure of usual hours in the previous year, but it is possible to identify which individuals were working mainly full time in the previous year.

The education categories in the Canadian censuses for 1981-2001 are based on grades attended and degrees and diplomas received, like the United States surveys after January 1992, and are consistent over time. The detailed categories in the "highest level of schooling" variable can be divided into four groups that broadly correspond to Jaeger's four groups for the United States.[10] A consistent education series can be constructed for four education groups in the Canadian censuses for 1981-2001 that correspond to the four groups in the US data. The closest, almost exact, correspondence is for the university graduates group, particularly after the relatively minor US break in 1991 when it is possible to know whether the individual actually received a BA degree or higher.

The correspondence is less exact for the groups below BA. The census documentation makes it clear that "highest level of schooling" should not be interpreted in a strict hierarchical sense because of the difficulties of ranking various forms of "post-secondary" education categories. The census also records the highest grade attended whether or not this was the highest level of schooling. Examination of this, together with the highest level of schooling shows a strong pattern of "leap-frogging" in the highest level of schooling variable based on the post-secondary information. That is, for example, there is a substantial number of individuals whose highest grade was as low as 5-8 that, on the highest level of schooling variable, rank above individuals who graduated from high school. This leap-frogging is due to the receipt of post-secondary certificates below the university degree level. Thus, some caution is needed in cross country comparison at the level of the education groups below a BA.

The main disadvantage with the Census is that it does not provide an annual series.[11] However, an annual series is available from the LFS, starting in 1997.[12] The education definitions in the LFS are consistent throughout the 1997-2015 period, but differ somewhat from the definitions in the Canadian census. Four education groups, similar to the groups defined for the Canadian census

[10]Details of this division are given in the Appendix.

[11]The closest equivalent repeated cross section data source to the MCPS for Canada is the Survey of Consumer Finances (SCF). This survey, started in 1972, and held every second year became annual from 1982 to 1998 except 1984 and represents an annual survey measuring previous years earnings in a way similar to the MCPS. Unfortunately, there are several major problems in the SCF, especially of comparability over time, that are less of an issue in the MCPS. (See the Appendix for more detail.) Gu et. al. (2002) argue that for consistency over time the census education measures are preferable to the SCF measures and use the census for the Statistics Canada series on a composition adjusted labour input series for 1961-2000.

[12]Unfortunately, the monthly LFS did not begin to collect earnings data until 1997.

and for the US MCPS, are constructed from the LFS data to match the earlier period as closely as possible. The closest match occurs for university graduates where the measures are almost the same. Frequencies for the four education groups in the 1981 census and in the monthly LFS for 1981 are very close for the two highest levels of education and quite close for the two lowest groups. More detailed discussion is provided in the Appendix. However, the match is far from perfect and some caution is, therefore, warranted in interpreting estimated prices and quantities across the two data sources for Canada.

2.4 Estimated Price Series for Canada and the US

The most important problem to be solved in estimating the price series via the flat spot method is the choice of the flat spot regions in supplied efficiency units for the four education groups. The estimated price series using this method are sensitive to the location of the flat spot, primarily for college graduates. A final step is the choice of the length of the flat spot, and hence the number of cohorts that can be used to identify price changes between any pair of years. There is a tradeoff between the length of the flat spot and the sample size. The analysis in BR uses a flat spot length of 10 years, allowing the averaging of 9 cohort pairs across any two years in the US data. This is, perhaps, the minimum length that is feasible given the MCPS sample sizes. BR provide a framework for choosing the flat spot and estimate annual price series for four skill types for the U.S.[13]

Figure 1 presents the annual price series for the US for 1963-2015, normalized to one in 1975, for the four types of human capital or skills: high school dropouts, high school graduates, some college and university graduates. The price series in Figure 1 is an extension of Figure 3 in BR to 2015. This is the preferred price series for the US, based on median wages, largely to avoid problems due to time varying top-coding and allocation procedures in the US data.[14] A striking feature of

[13]The main assumption employed in using wage data to estimate the prices is that workers are paid their marginal product in each period. Biases for some groups could arise from contract wages and time varying incentive effects, as well as the problem of time varying top-coding and allocated values procedures. The standard literature associating relative wages with relative skill prices has discussed a number of these problems, including the complications arising from changing non-wage benefits, union rents and other influences on relative wages. Both composition adjustment approaches and BR use observed wages and are subject to these problems. Possible non-random participation due to retirement is perhaps a more specific concern for flat spot estimates. However, the use of flat spot regions not too close to retirement, and the supplementary confirmation from an alternative method (discussed in the web Appendix to BR) that uses a younger age group, goes some way to minimize this problem.

[14]The simplest application of the estimation methodology constructs the price series using mean log wage differences $\text{Mean}[\ln w_{t+1,i}] - \text{Mean}[\ln w_{t,i}]$ for observations in the flat spot range. However, in practice the chosen benchmark series in BR uses median wages. The primary reason for preferring medians for the US price series is the time varying treatment of top-coding and allocated values in the MCPS. However, the basic pattern of the estimated price series is robust to alternative wage measures, sample restrictions and estimation methods. See the Web Appendix of BR for

Figure 1 is the close correspondence in the series for such diverse education groups as high school dropouts and college graduates. Over short intervals, there is some movement in relative prices, but any gaps tend to disappear quite quickly. All four groups are closely related most of the time except for the pattern of the dropouts tending to suffer larger price declines in recessions, though these are recovered within a few years.

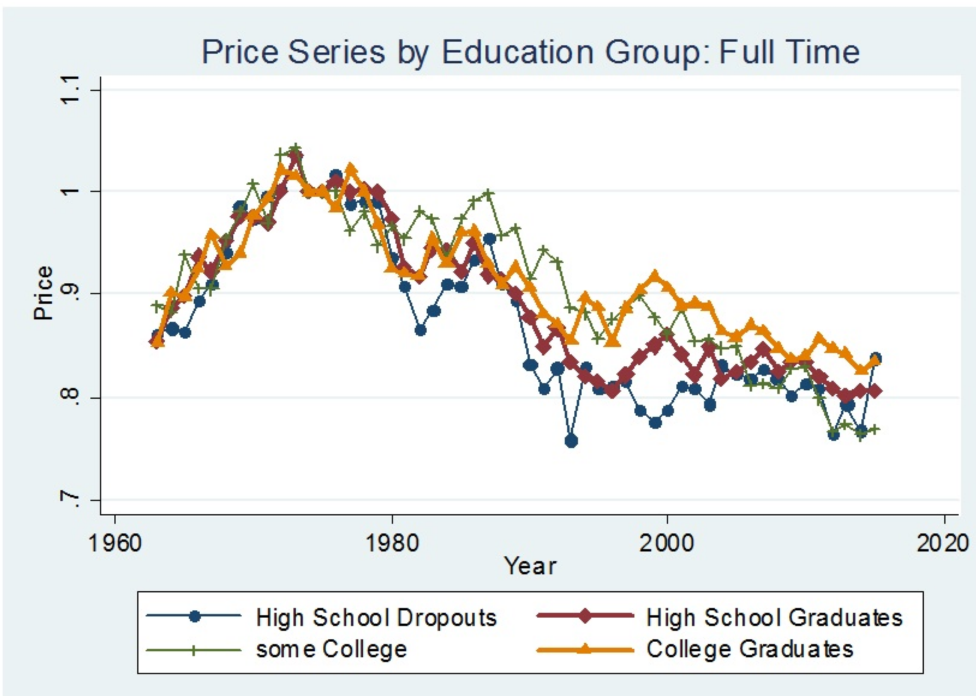


Figure 1: US Price Series 1963-2015

The sample sizes for Canada are larger, but the data set for the 1980 - 2000 period, rather than being annual as in the MCPS, is every five years which reduces the number of cohort pairs that can be used in the flat spot estimation from 9 to 5. A flat spot method, corresponding as closely as possible to the method used for the US, was applied to the Canadian census data set for the 1980-2000 period by following the same five year cohort group across adjacent five year censuses, such

more details. The series based on medians are not affected by time varying top-coding, but series based on average log wages are. However, as long as top-coding and the switch to replacement values in the mid 1990s are appropriately dealt with the series based on average log wages are very similar to those based on medians. See Bowlus, Bozkurt, Lochner and Robinson (2016) for a full analysis.

that in both censuses the age range of the cohort group remains within the ten year flat spot. Thus, using a 10 year flat spot of 50-59 for college graduates, in the annual US data, college graduates age 50-58 in year t are followed to age 51-59 in year $t+1$. By contrast, in the Canadian data, the college graduates age 50-54 in year t are followed to age 55-59 in year $t+5$. In order to assess any systematic differences that might occur from using five year rather than one year intervals, that would complicate Canada-US price series comparisons, the price series for the US were recomputed using the same MCPS data, but restricting the data to five year intervals. The results were quite similar.[15]

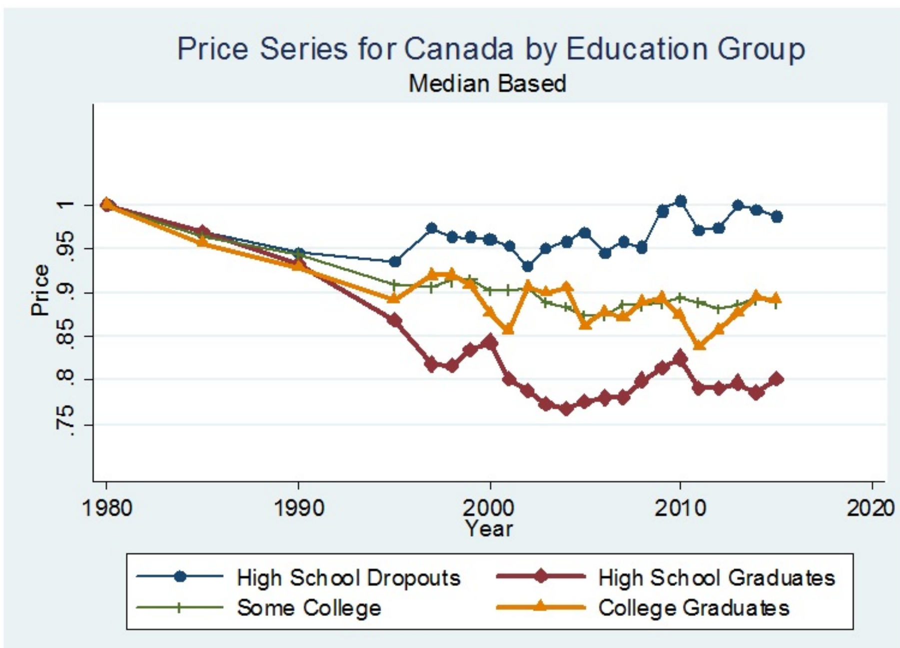


Figure 2: Canadian (Median Based) Price Series 1980-2015

The Canadian series is extended beyond 2000 by using the same procedure that BR applied to the MCPS to the Canadian monthly LFS, using the same flat spot regions. The LFS series for 1997-2015 is spliced to the Canadian census series for 1980-2000 by normalizing the LFS series to

[15]See the Appendix for details.

the values of the census series in the overlap earnings year, 2000. The Canadian series are consistent within the 1980-2000 period of the census data, and within the 1997-2015 period of the LFS, but, as noted earlier, there is a potential break between the series for the education groups below university graduates.

Figure 2 plots the price series for Canada for the period 1980-2015 using medians for all years. The prices all decline by similar amounts until 1995. There is some deviation after 1995, though by 2000 all but the dropouts have converged again to similar values. High school graduates appear to be substantially affected by the early 2000s recession, though by 2010 their price series is again close to the some college and university groups. Dropouts are the exception. There is some decline in the early 2000s recession, but they recover much earlier and are then roughly constant throughout the remaining period.

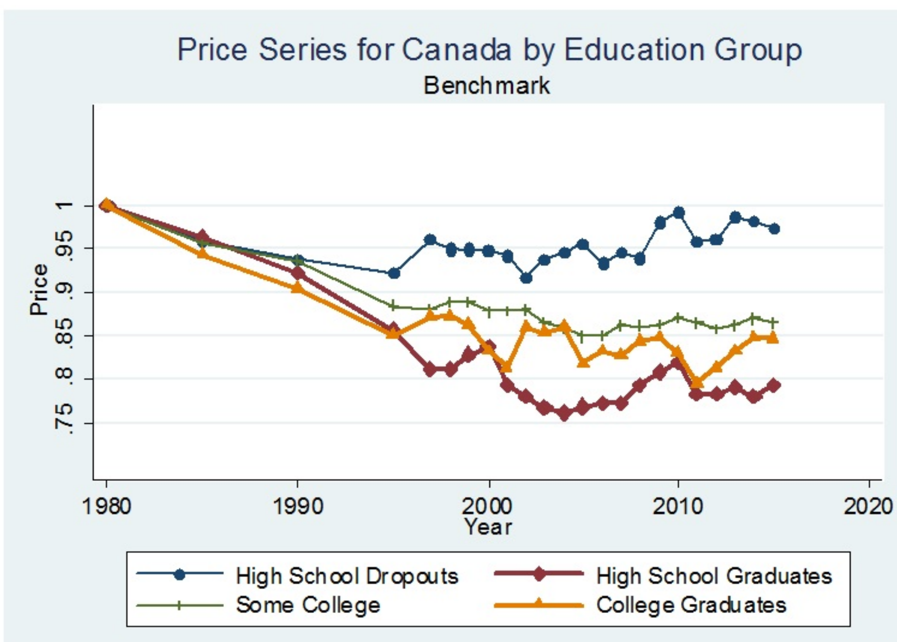


Figure 3: Canadian Benchmark Price Series 1980-2015

As noted above, very similar price series are produced using either medians or average log wages in the US data provided the problems of time varying top-coding and allocation methods are dealt with. The Canadian series estimated from annual LFS data for 1997-2015 also are essentially the same whether median or average log wages are used except for the dropout group where they begin to separate in the mid 2000s. However, the series using Census data are sensitive to the use of medians or average log wages for the higher education groups. For all groups there is a decline in the price from 1980, but the median series series shows a smaller decline, especially for the higher education groups. The difference is minor for the lower education groups.

While the census education group break between 2000 and 2005 affects the education groups below a BA degree, for the university group we can compare the census price change from 2000 to 2005 with the LFS. If we smooth the LFS series with a 3 year moving average and compare the census and LFS changes between 2000 and 2005, a simple average of the median and average log based price series from the census is very close to the estimated change from the LFS. A "benchmark" Canadian series is constructed that takes a simple average of the median and log based series from the census period and splices this with the median based series from the LFS. For all but the university group this is very similar to the series that uses medians throughout. The benchmark series is plotted in Figure 3.

A direct comparison between the US and Canada is shown in Figure 4. The major difference between the countries is the much larger relative decline, especially from 1980 to 2000, in the prices for university graduates compared to the lowest education groups. Comparing university with high school graduates, Table 1 shows that Canada and the US have roughly similar drops for the high school and some college prices, but the US has a much smaller drop in the university price, producing a relative price increase in the US, but not in Canada. Even more extreme is the comparison with dropouts where, since US dropouts experience a much larger fall in the price than Canadian dropouts, there is a relative price decrease in Canada compared to a relative price increase in the US.

3 Relative Wages and Skill Supplies: the Canonical Model Framework

The canonical model assumes (at least) two skill types, high and low, that are imperfectly substitutable in production, and competitive labor markets. Following the notation of Acemoglu and

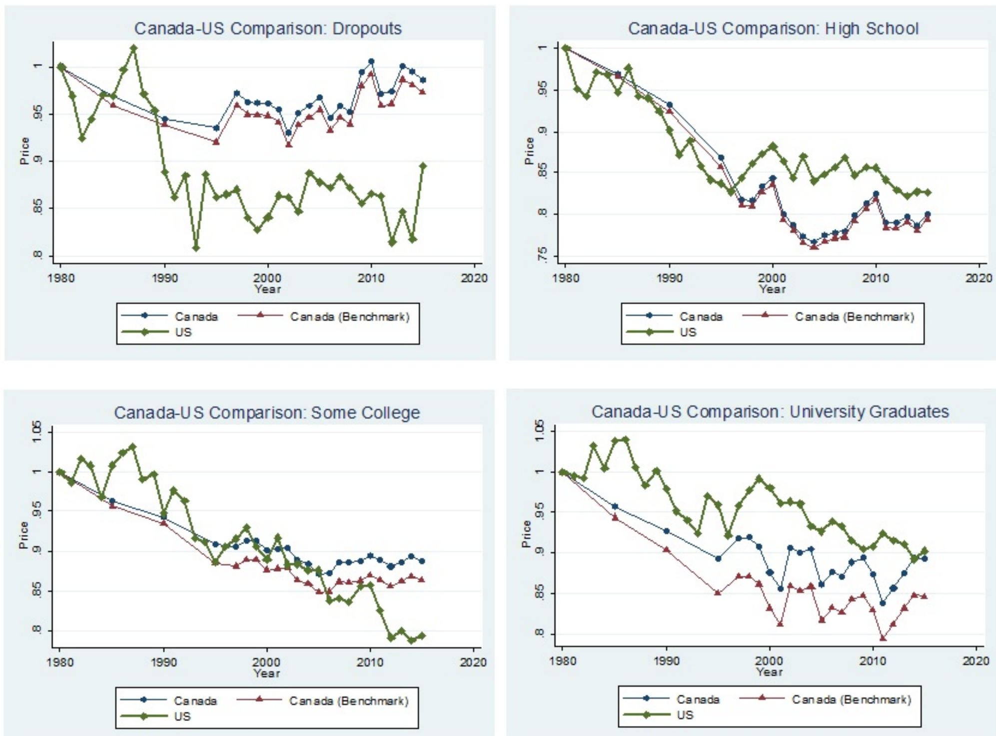


Figure 4: Canada-US Price Series Comparison 1980-2015

Autor (2011), output is produced according to the CES production function:

$$Y = [(A_L L)^{\frac{\sigma-1}{\sigma}} + (A_H H)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}, \tag{3}$$

where L is the total input of low skill and H is the total input of high skill. The basic parameters are A_L and A_H, which scale the skills and set the technology, and $\sigma \in [0, \infty)$, the elasticity of substitution. Factor augmenting technical change is captured by changes over time in A_L and A_H.

The competitive labor market assumption implies that firms will set the value of the marginal product of L equal the *unit* wage or *price*, w_L, for low skill (i.e. payment for one unit of L), and similarly for H which yields the relative demand function:

$$ln(H/L) = (\sigma - 1)ln(A_H/A_L) - \sigma ln(w_H/w_L). \tag{4}$$

The demand curve has an intercept (at equal factor prices), $(\sigma - 1)ln(A_H/A_L)$, that may shift over time due to SBTC, i.e. changes over time in $ln(A_H/A_L)$, and a slope, $-\sigma$, with respect to the relative prices. Equation (4) may be re-arranged to yield the skill premium equation:

$$ln\omega = ln(w_H/w_L) = \frac{\sigma - 1}{\sigma}ln(A_H/A_L) - \frac{1}{\sigma}ln(H/L). \tag{5}$$

3.1 Relative Prices, Relative Wages and the Canonical Model

Equation 5 has been used to explain the rise in the university premium in the US, which has been a major part of the increase in inequality. However, the w_H and w_L in the canonical model are *unit* wages or prices, which may be different from composition adjusted wages, and the L and H in the canonical model are the true quantities which may be different from the composition adjusted quantities. Bowlus *et al.* (2016) revisit the canonical model with an explicit recognition of potential differences between relative prices and relative composition wages, allowing for average quantity changes within skill type due to cohort effects.[16] Let L and H differ from "composition adjusted" L_c and H_c quantities used in the standard implementation of the canonical model such that $L = B_L L_c$ and $H = B_H H_c$ where B_L and B_H capture the cohort effects of BR due to technological change in human capital production and selection effects. This introduces a distinction between prices (unit wages) and (composition adjusted) wages. The B_L and B_H terms measure the average number of units of L or H supplied by a (composition adjusted) unskilled or skilled worker, or worker 'hour' depending on the units chosen.

The production function is the same as before but in terms of the composition adjusted quantities and the additional parameters, equation (3) is re-written:

$$Y = [(A_L B_L L_c)^{\frac{\sigma-1}{\sigma}} + (A_H B_H H_c)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}},$$

and equation (5) may be re-written:

$$ln\omega = ln(w_H/w_L) = \frac{\sigma - 1}{\sigma}ln(A_H/A_L) - \frac{1}{\sigma}ln(B_H/B_L) - \frac{1}{\sigma}ln(H_c/L_c) \tag{6}$$

Alternatively, generating the first order conditions in units of the composition adjusted wage, equation (5) may be re-written:

$$ln\omega_c = \frac{\sigma - 1}{\sigma}ln(A_H/A_L) + \frac{\sigma - 1}{\sigma}ln(B_H/B_L) - \frac{1}{\sigma}ln(H_c/L_c) \tag{7}$$

[16] These cohort effects are due to time varying selection effects in who goes on to higher education, and to secular technological change in human capital production. The technological change in human capital production is assumed to be always positive for the high skill because of the advance of knowledge, but may be zero or negative for the low skill reflecting progress or regress in the school system. The selection effects are governed by the size of the ability-education level correlation and the cohort fraction of high and low skill. For more details see BR.

where $\omega_c = \frac{w_{H_c}}{w_{L_c}}$ is the relative wage premium of the composition adjusted inputs. Note that in equation (7), the term $ln(B_H/B_L)$ plays exactly the same role in determining the wage premium, $ln\omega_c$, as the SBTC term, $ln(A_H/A_L)$. However, while the SBTC affects relative wages by shifting the relative demand, $ln(B_H/B_L)$ affects relative wages by shifting the relative average quantities of the two skill types, i.e. it adjusts for average quality changes within each skill type.[17]

Using this framework, differences in the paths of relative prices across countries are examined in terms of differences in the paths of the SBTC terms, as well as in relative supplies, $ln(H/L)$ and σ in equation 5. Differences in the paths of relative (composition adjusted) wages, i.e. the university premium, are examined in terms of the components of equation 7.

3.2 Interpretation of the Different Relative Price Paths Across Countries

In the canonical model the path of prices is explained in terms of changes over time in SBTC and skill supplies (quantities). While SBTC is not directly observed, relative skill supplies can be constructed. One significant difference between the two countries over this period relevant for the path of relative skill supplies is the large difference in the skill pattern of immigration. The implications of this difference for relative wages were recently analyzed in Borjas and Aydemir (2007) within the framework of the standard canonical model. Borjas and Aydemir (2007) estimate the effects of the relatively large scale "immigration shocks" to both countries in the 1980-2000 period. They show a large negative wage effect for university educated workers in Canada, but not in the US due to the very different pattern, by education, in the increased supply of university educated workers through immigration. Indeed, the direction and magnitudes of the effects reported in Table 4 in Borjas and Aydemir (2007) are close to the price differences shown in Figure 4.

Card and Lemieux (2002) present some cross country evidence on SBTC for the earlier period using a version of the canonical model with imperfect substitution across age groups within skill. While the parameters for the US and the UK were quite similar and estimated with some precision, it was not possible to obtain precise estimates for Canada. Bowlus, Bozkurt, Lochner and Robinson (2016) show that implementation of the canonical model with prices and quantities of the type used in this paper that incorporate cohort effects yield a much better fit for the out of sample predictions of the original simple canonical model and do not require imperfect substitutability across age groups. We compare estimates of SBTC for Canada and the US using these prices and quantities.

[17] Bowlus *et al.* (2016) refer to equation (7) as the augmented canonical model.

Green and Sand (2015) argue that boom periods in the natural resources sector in Canada play an important role in shifting relative demand for low skilled workers. Relative demand shifts in the standard canonical model come from SBTC. The model does not explicitly have different output sectors. However, relative demand shifts of the type discussed in Green and Sand (2015) may show up as SBTC differences in Canada compared to the US.[18]

INCOMPLETE - ESTIMATES OF THE MODEL PARAMETERS TO FOLLOW

4 University Wage Premium and Inequality Paths: Decomposition of Prices and Quantities

The large increase in the university premium in the US from the late 1970s to the mid 1990s was a major part of the overall increase in inequality in this period for the US. This increase was driven in part by an increase in the relative price for university graduate human capital. Figure 4 shows that, unlike the US, the price for university graduates in Canada did not increase relative to that of the lower education groups. In this section we investigate the effect this different price path had on the path of the university wage premium in Canada compared to the US.

The canonical model gives us the sources, if not a full explanation, of the cross country price path differences, and hence the source of the part of the relative wage path differences due to prices. That leaves the relative wage path differences due to differences in the paths of per worker (hour) efficiency units of human capital within skill or education group. For each country the price and efficiency units series are identified up to a normalization. For our comparative analysis, the normalization sets the price of each type of human capital in each country equal to one in 1980. This implicitly normalizes efficiency units, $E_s(c)$, for a worker from cohort c with experience s for each type of human capital to the wage of that type of worker in 1980. Within country, this normalization is innocuous and allows the identification of changes, relative to 1980 levels, in prices and quantities for each of the four human capital types, and therefore of changes in relative prices or quantities across skill levels. Across countries, however, the normalization is not innocuous. As discussed in Section 3, the relative price across countries for any human capital type in 1980 is not identified. This rules out comparison of levels of efficiency units across countries, but still allows for the identification of relative changes in efficiency units across countries.

[18]Green and Sand (2015) also note important institutional differences between the two countries that can affect the path of relative wages. We discuss these in Section 6 below.

4.1 The University Wage Premium

The previous literature has documented a very different path for the university wage premium in Canada compared to the US, resulting in a smaller rise in income inequality in Canada. Card and Lemieux (2001) showed the increased university premium for males in the US, interpreted as the skill premium in the standard implementation of the canonical model, was largely confined to younger workers. In BR this increasing "skill" premium for the younger male university graduates in the US, documented in Card and Lemieux (2001), was decomposed into price and per worker quantity effects. Figure 5 reproduces this decomposition and shows that price and quantity both had an effect in increasing this measure of inequality. The rapid increase in the university premium from 1980 to the mid 1990s was in part due to a significant increase in the relative price, though the majority of the increase was due to a large change in the relative quantities supplied.

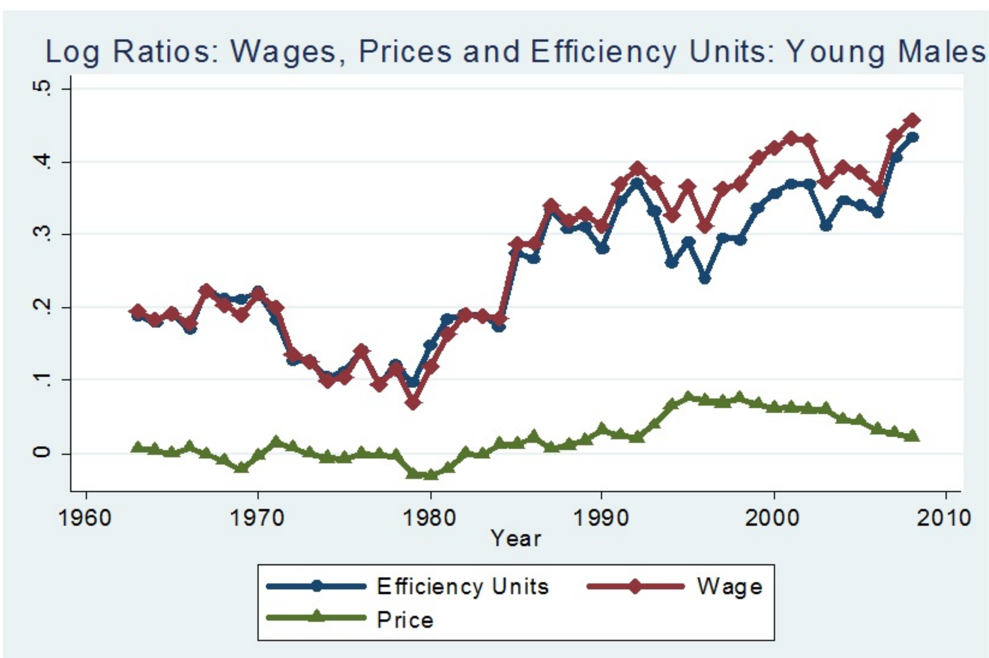


Figure 5: Decomposition of the US University Premium

The analysis is repeated here for Canada and compared to the US. First, the Canadian census data are used to examine the important 1980-2000 period. The Canadian Census uses a consistent definition of both high school and university graduates throughout 1980-2000. Table 1 shows the well documented much larger increase in the relative wages of university graduates in the US compared to Canada, especially up to 1995. For the entire period, 1980-2000, in the US the log gap increased by .3001, while in Canada the increase is only .1804 log points. Up to 1995 there is an even starker difference of .2476 for the US compared to only .0606 for Canada.

Log Relative University/High School Ratios
Younger Workers: 26-30

	Canada			United States		
	Wage	Quantity	Price	Wage	Quantity	Price
1980	0.1535	0.1535	0.0000	0.1186	0.1186	0.0000
1985	0.1761	0.1980	-0.0218	0.2869	0.2441	0.0428
1990	0.2121	0.2334	-0.0213	0.3130	0.2506	0.0624
1995	0.2141	0.2206	-0.0064	0.3662	0.2592	0.1070
2000	0.3339	0.3387	-0.0047	0.4187	0.3270	0.0917

Table 1: Decomposition of the University Premium: Canada and the US

In both countries the source of the increased university wage premium is predominantly the increased relative quantities of efficiency units supplied by university graduates compared to high school graduates. For the US .0917 of the .3001 increase is due to price, and for Canada, none is due to price. In fact, the relative growth in per capita efficiency units supplied by university graduates is only a little behind the growth for the US (.1852 vs .2084). Thus, over the 1980-2000 period the human capital of Canadian male university graduates relative to high school graduates improved at a similar rate to that of US male university graduates, but their relative wages grew more slowly because they received a lower relative price for their human capital, consistent with the "immigration shock" differences across countries to the relative supply of university human capital. In summary, the slower increase in inequality between young university and high school graduates in Canada relative to the US is due to the absence of any relative price increase in Canada.

Figure 5 shows that the relative price increase stopped in the US in the mid 1990s and was no longer a source of increasing inequality between college graduates and high school graduates. A comparison for the period after 2000, when there is a break in the education coding in the Canadian census, can be made using a measure of hourly earnings from the LFS for the 1997-2015 period in which the education definitions are constant. A similar weekly earnings measure is available in the Merged Outgoing Rotation Groups (MORG) data from the US Current Population Survey which also has similar consistent education measures.

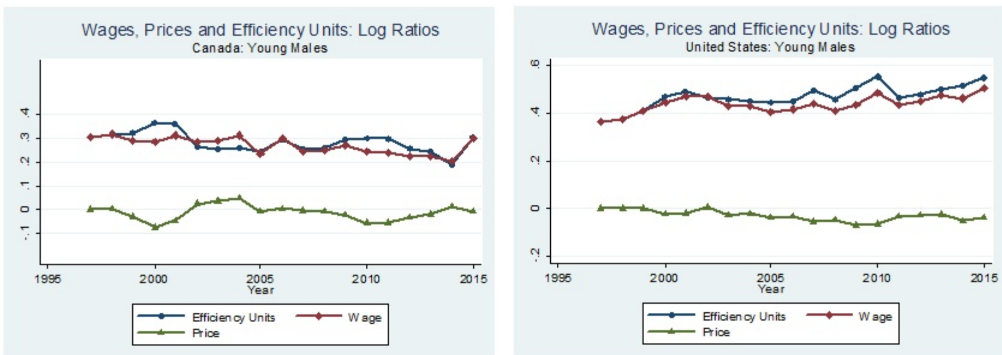


Figure 6: Decomposition of the University Premium 1997-2015

Figure 6 plots the decomposition of the relative wages for young male university graduates into relative price and quantity components for the 1997-2015 period using the LFS for Canada and the MORG for the US. The relative price paths are much more similar for the two countries after 2000. The large relative price increase for university graduates in the US for the earlier 1980-2000 period (Table 1) compared to university graduates in Canada is absent for the 2000-2015 period. The university wage premium continues to increase in the US, but at a much slower rate than for the 1980-1995 period. Differences in the path of relative prices in the two countries is no longer the main driver of differences in relative wages of university graduates.

5 Human Capital in Canada and the US: Life-cycle Production and Cohort Effects

The cross country patterns in per worker efficiency units of human capital, that influence the different paths of wages and inequality in the two countries, can be interpreted within the human capital framework of BR and the extension in Bowlus and Robinson (2016). The production of human capital in each country is assumed to be the result of optimal investments in human capital over the life-cycle, subject to the constraints imposed by the relevant environments in each country, reflecting possibly different education and taxation systems, as well as potentially different time paths in the prices for the different types of human capital.

BR uses a combination and extension of the discrete time Ben-Porath based models used in Heckman, Lochner and Taber (1998) and Kuruscu (2006). The model has heterogeneous human capital ("skills"), associated with different schooling groups, that command different prices. In choosing a specific schooling level, individuals choose a specific skill and an associated production function for post-school investment. Individuals differ in their initial endowed ability. Higher ability level individuals choose a higher level of schooling, produce more human capital at each schooling level, and are more productive in post-school investment. As in Heckman, Lochner and Taber (1998), the individual's choice problem can be thought of in two stages: condition on a schooling level and optimize the post-schooling investment profile given the on-the-job production function (and type of human capital) associated with that schooling level; then select among schooling levels.

A key aspect of the analysis in BR, and the extension to a structural model in Agopsowicz, Bowlus and Robinson (2016) is the incorporation and measurement of important cohort effects induced by technological change in the human capital production functions, and selection effects based on completed education levels by cohort. There are two sources of cohort effects in BR: (1) effects arising from heterogeneity in ability and (2) effects arising from technological change, broadly interpreted, in the production of the different types of human capital. A third source of cohort effects introduced in Bowlus and Robinson (2016) is the increased incentive for females to invest in human capital following the large secular increase in their participation rates.

Most males work full time and participation rates have not shown any major changes over the last three or four decades. For simplicity, the optimal life-cycle investment problem for males in BR ignores labor supply issues. For females, however, a substantial fraction work part time and there have been dramatic changes in participation rates. To account for these features, the optimal life-cycle investment problem is amended in Bowlus and Robinson (2016) to incorporate shifts over time in labor supply.

Following the notation of Bowlus and Robinson (2012), let the total length of the period be 1 and define $n_s = (1 - l_s)$ as the fraction of the total period available for allocation between investment in human capital production and efficiency units supplied to the firm, for an s-year experienced worker, where i_s is the fraction of "hours at work" devoted to human capital production, and l_s is leisure or home production time. Total earnings in the period are given by $\lambda h_s n_s(1 - i_s)$, and total efficiency units supplied to the firm are $E_s = h_s n_s(1 - i_s)$, where λ is the price of human capital and h_s is the level of human capital of an s-year experienced worker.

The problem of how much human capital to produce in each period can be characterized in terms of comparing marginal cost and marginal revenue of producing human capital in each period. Allowing for labor supplied to be less than the full period introduces a dependence of the marginal revenue on the labor supply not present in BR. The MR_s depends on the interest rate, labor supply and the length of the working life and declines with experience:

$$MR_s = \lambda[\frac{n_{s+1}}{1+r} + \frac{n_{s+2}}{(1+r)^2} + \ldots + \frac{n_T}{(1+r)^{T-s}}]. \tag{8}$$

MC depends on the production function, but is constant with respect to experience under the neutrality assumption. A declining path for human capital production is traced out by the intersection of the declining MR_s with the fixed MC. The life-cycle profile of E_s follows from the path of human capital production and hence depends on the properties of MR_s and MC.[19]

The simplifying assumption for males used in BR is $n_s = 1$. The model generates a peak in E_s for males in the later part of the working life. This is important for implementation of the flat-spot method for identifying human capital prices. For females, however, it is necessary to relax this assumption. For at least some periods for many females, $0 \leq n_s < 1$. This implies differences in the life-cycle paths of supplied efficiency units, E_s. In particular, for periods of non-participation, $n_s = 0$, so that MR_s is typically lower for females, implying lower investment and therefore production of human capital.

In BR, cohort effects are introduced into the framework via changes in education patterns and the human capital production functions for different cohorts. As in Heckman, Lochner and Taber (1998), an individual's ability affects the amount of human capital they produce in the schooling phase and hence their stock at the start of the post-school phase. In choosing a schooling level in the first stage of the life-cycle optimization problem, individuals with higher ability choose higher levels of education. This induces cohort effects due to selection on ability within a cohort into college. Assuming a common initial ability endowment distribution across cohorts, changes in the fraction of a birth cohort whose highest level of education is a college degree imply changes in the mean endowed ability of the college graduates from that cohort.[20] This effect is incorporated by allowing

[19]See BR for more details.

[20]It should be noted that this is not an innocuous assumption. The initial endowment distribution is determined both by attributes at birth and the influence of early childhood factors in the household which may change over time.

the human capital stock (for each human capital type) at the start of the post-school phase, $h_0(c)$, to vary by birth cohort, c.[21] For example, for college graduates, other things the same, a decrease in the fraction of the birth cohort with a college degree increases $h_0(c)$, and hence, increases $E_s(c)$ for any experience level.

Similarly, cohort effects due to secular technological changes in the production of human capital are incorporated by allowing the schooling phase production function for college graduates to improve over time with advancing knowledge, resulting in a higher $h_0(c)$ and hence, increased $E_s(c)$ for any experience level for more recent cohorts. In addition to cohort effects from selection and technological improvements in human capital production that apply to both males and females, Bowlus and Robinson (2016) allow for the optimal life-cycle $E_s(c)$ profile to shift up for female cohorts with greater (planned) participation.

Within this framework, differences in the human capital stocks of the two countries may result from a variety of sources. First, there are substantial cross country differences in education systems, in expenditure on education and education subsides at various levels, as well as a different mix of private and public provision. This implies potential differences in the underlying production function, and the rate of technological improvement in human capital production. Second, there are substantial differences in student loan systems and the effective tax rate on human capital investment.[22] These imply potential differences across countries in the life-cycle paths of supplied efficiency units, E_s, and hence, human capital stocks, for each of the education groups. Third, there are differences in the levels and the time path of the secular increase in educational attainment across the two countries, as well as differences in the correlation between measures of ability and completed education level.[23] Finally, there are differences in the time path of participation patterns. These differences, and the potential difference in the rate of technological improvement in human capital production imply potentially different cohort effects in the two countries, i.e. differences in $E_s(c)$, which have implications for the path of the university premium and inequality in the two countries.

[21] Effects through selection on the "ability to learn" in the post schooling phase could also be allowed.

[22] See Belley, Frenette and Lochner (2014) and Burbidge, Collins, Davies and Magee (forthcoming).

[23] See Belley, Frenette and Lochner (2014) for evidence on the cross country differences on the relationship between ability measures and attendance at post-secondary institutions.

5.1 Cohort Effects on Life-cycle Human Capital Profiles

In BR, the quantity increase for university graduates over the period of the rapidly increasing skill premium reflects cohort effects due to technological improvement in the production of human capital, and to selection of better university graduates from the initial endowment distribution as the cohort fraction of university graduates declined rapidly from its peak in the 1946 birth cohort. The

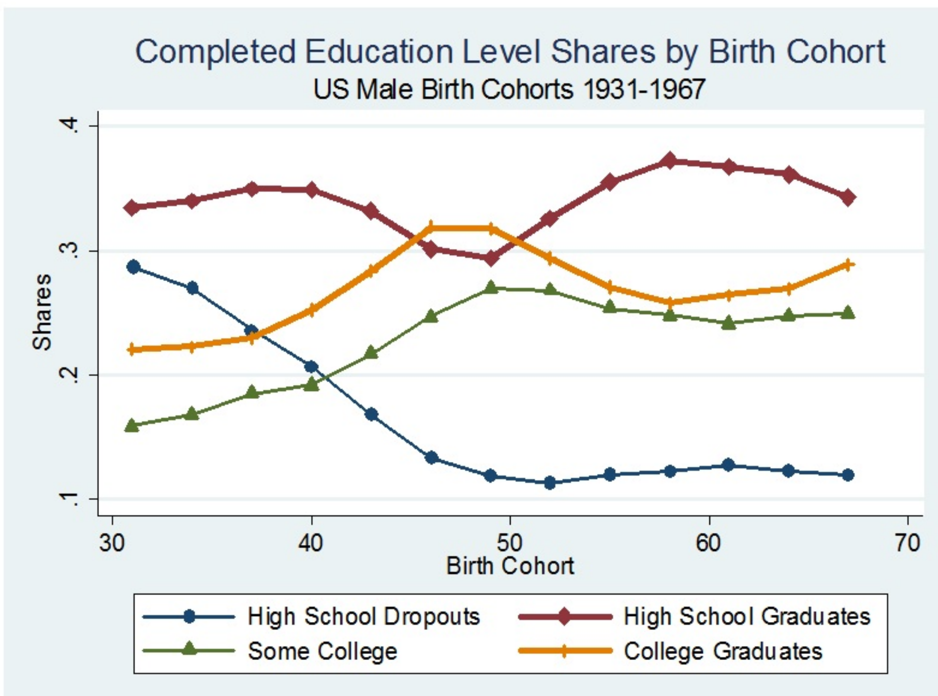


Figure 7: Completed Education for Males by Cohort: US

magnitude of the selection effects depends on the correlation of "ability" and completed education, and the time path of completed education by birth cohort. Figure 7, reproduced from BR, shows a large increase (50 percent) in the fraction of university graduates from the birth cohorts of the mid 1930s to the 1946 birth cohort, followed by a substantial drop to a trough with the 1958 birth cohort, before a recovery.

Figure 8 reports completed education by cohort for Canadian males, estimated from the census data, and 9 compares the fraction with a university degree for the two countries. The qualitative

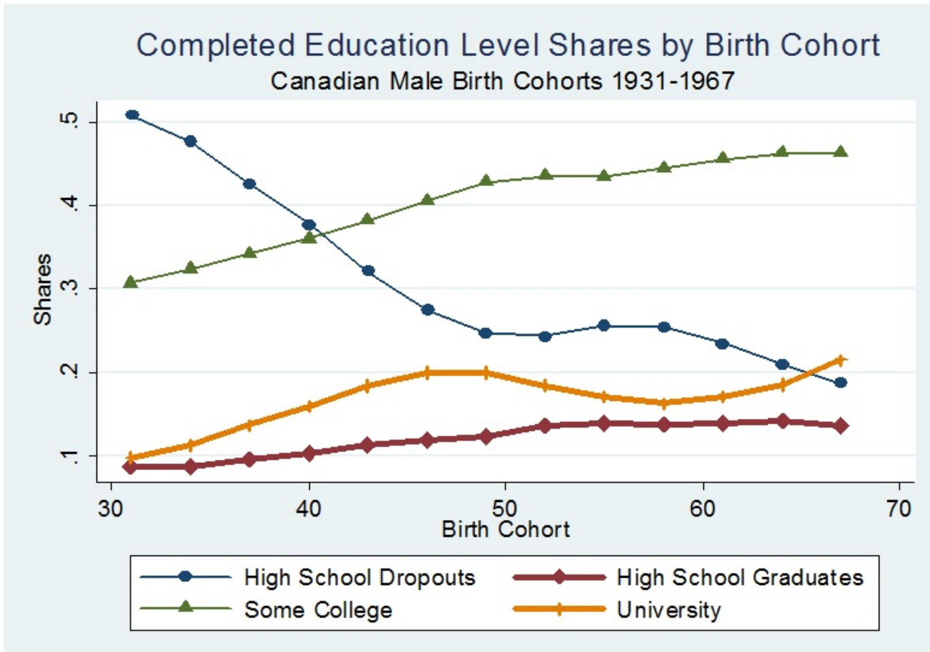


Figure 8: Completed Education for Males by Cohort: Canada

pattern for university graduates is very similar across countries, though the levels are quite different.[24]

A more detailed picture of the sources of efficiency units differences in Canada and the US can be obtained from estimating the life-cycle human capital profiles for the same birth cohorts in the two countries. Identifying the life-cycle profile of the (supplied) quantity of human capital, E_s, from wage data requires identification of the price. Even with panel data on wages, following a cohort, c, over time does not identify the profile of $E_s(c)$ unless the price is constant over the lifetime. In almost all of the literature on life-cycle earnings a constant price is a maintained assumption.[25] However

[24]University graduates are a much smaller share of the total in Canada than in the US. At the other extreme, dropouts are a much larger fraction in Canada. While dropouts in the US are not much above 10 percent by the 1946 birth cohort, at that point in Canada they are still not much below 30 percent and do not fall below 20 percent until the 1967 birth cohort. The high school graduates and some college groups are more difficult to compare across the two countries because of the different definitions used.

[25]The main exception is Heckman, Lochner and Taber (1998). More recently Huggett, Ventura and Yaron (2006) relaxed the constant price assumption and assumed a constant rate of growth for the rental rate equal to the average

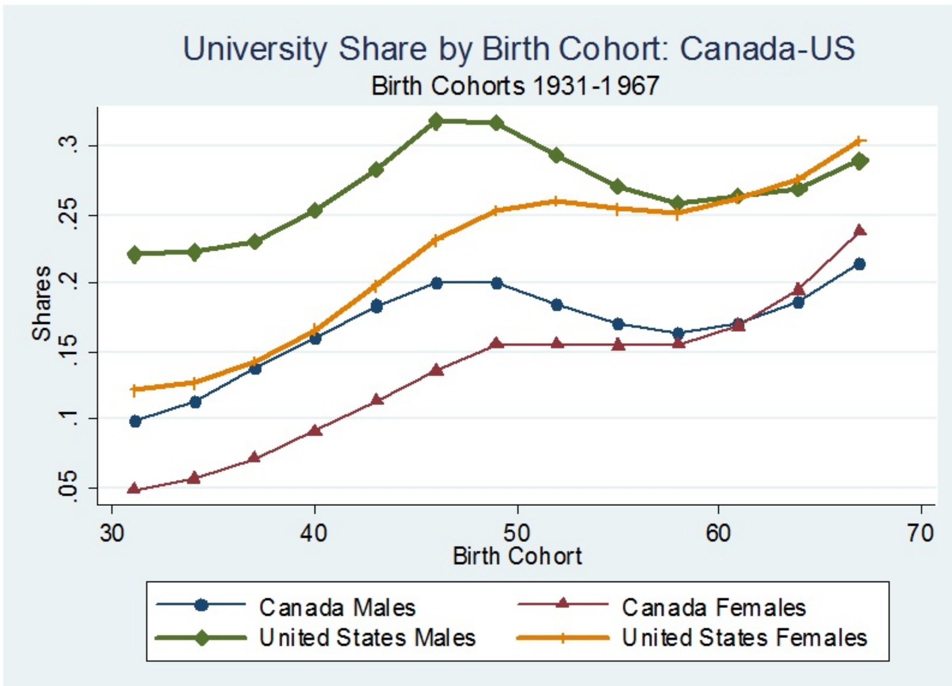


Figure 9: University Education by Cohort: Canada vs. US

Figures 1 and 3 indicate that the rental price is not constant in either country. In fact, the evidence suggests that the price movements have been large in the last three or four decades in the US, and of a similar magnitude for Canada for the shorter period that the series can be computed.

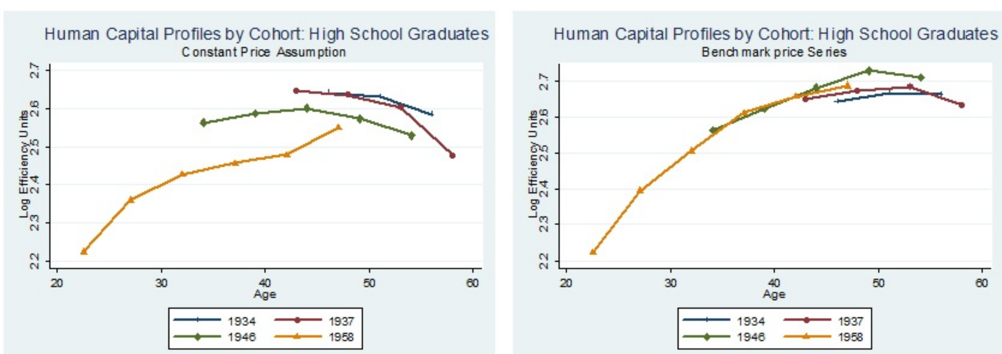
BR compared the estimated human capital profiles for each education group for a variety of birth cohorts whose wages are observed in the 1963-2008 period using the benchmark price series with the implied profiles using the standard constant price assumption in the literature. The results showed that, under the constant price assumption for high school graduates, for example, the life cycle human capital profiles, $E_s(c)$, are difficult to make sense of within a standard Ben-Porath model.[26] They have different shapes and often cross. The 1925 cohort appears to have continued to grow quite rapidly to age 53; the 1937 cohort shows rapid growth to age 40 and then declines. Moreover, the

growth rate in mean real earnings. Guvenen and Kuruscu (2007) take a similar approach in calibrating their model of inequality.

[26] All of the life-cycle analysis is done for males only. A full analysis for females needs to deal with the selection arising from a different life-cycle participation pattern.

1958 profile is dramatically worse than the 1946 profile, with a twenty to thirty percent difference for most ages up to the early 40s. By contrast, using the benchmark price series, the pattern represents a sequence of cohort profiles all with the classic Ben-Porath shape. Instead of varying shapes and profile crossing, the profile shapes are much closer to each other and to a standard concave profile. The benchmark price series produces these readily interpretable sequences of concave profiles across cohorts for all education groups.[27]

A similar life-cycle analysis is conducted for Canada using the Census data, and the cross country differences are interpreted within the BR framework. The analysis is, unfortunately, much more limited for Canada because of the later start date for the price series (1980 vs. 1963). It is not possible to use birth cohorts much before the late 1930s. The left hand panel (a) of Figure 10 reports the profiles for high school graduates using the constant price assumption. The right hand panel (b) uses the benchmark price series. While the range of birth cohorts and overlap is too small to see the confused crossing observed in the US analysis with the earlier birth cohorts, there is again a sequence of relatively very smooth profiles with the classic Ben-Porath shape using the benchmark price series. A prominent feature of the comparison is that, as for the US, the use of the benchmark removes a very large gap between the 1958 and 1946 birth cohorts.



(a) (b)

Figure 10: Life-cycle Efficiency Units Profiles for Canadian High School Graduates

[27]The 1958 cohort of high school graduates is still somewhat below the 1946 cohort, but the gap is much smaller using the benchmark series. For college graduates, technological change in production of human capital is assumed to be dominated by the advancement in knowledge and is thus assumed to be positive. However, for the other groups, given substantial changes over time in the highly regulated education sector that influence how resources are used, there could be also be technological regress for these groups. This could account for the residual difference between the 1946 and 1958 cohorts for high school graduates and dropouts.

The college premium increased from 1980 to 2000 in both countries primarily for young university graduates.[28] As reported in Table 5, the decomposition of the young college premium, shows that the major source of the premium increase is the the increase in relative quantities rather than in relative prices. The actual efficiency units for the median young male Canadian university graduate in Table 5 shows a 13.8% increase; the pattern is similar for the US. In the BR framework the increased efficiency units for young male university graduates reflect cohort effects due to time varying selection into university and technological improvement in human capital production. These effects may be seen by plotting the human capital profiles for different cohorts and approximate magnitudes of the cohort effects may be simply estimated, as in BR, using a standard parametric form for the human capital profiles.

5.2 Estimating Cohort Effects on the Life-cycle Human Capital Profiles of University Graduates

Different vintages of university graduates may have different types of human capital or different amounts of the same type. The maintained hypothesis in BR is that university graduates have the same type of human capital across cohorts and therefore that shifts across cohorts in human capital profiles reflect different amounts of the same type of human capital associated with different vintages of university graduate. The human capital profiles, $E_s(c)$, for Canadian male university graduates, using the benchmark price series is plotted in Figure 11. As shown in BR with a longer price series, the pattern of human capital profiles, $E_s(c)$, over cohorts is close to a set of concave profiles with cohort effects due to selection or technological progress that shift the profiles up or down. The direction and magnitudes of the shifts is examined in more detail, as in BR, by imposing a common quadratic specification for the $E_s(c)$ profiles in experience for college graduates for as many three year birth cohorts as possible given the span of the data and estimating the cohort intercepts. The results for both countries are shown in Table 2.

The omitted cohort is 1946 (1945-1947) which, in terms of cohort effects due to selection, is the turning point in both Canada and the US. The results from BR using cohorts from 1937 to 1961 over the age range (30-45) shows a pattern of cohort intercepts, relative to 1946, that is exactly what would be expected from the simple specification of cohort effects above. By assumption for cohorts after 1946, the effects due to technological improvement in human capital production are

[28] In fact, for Canada the premium for older university graduates actually fell over the period.

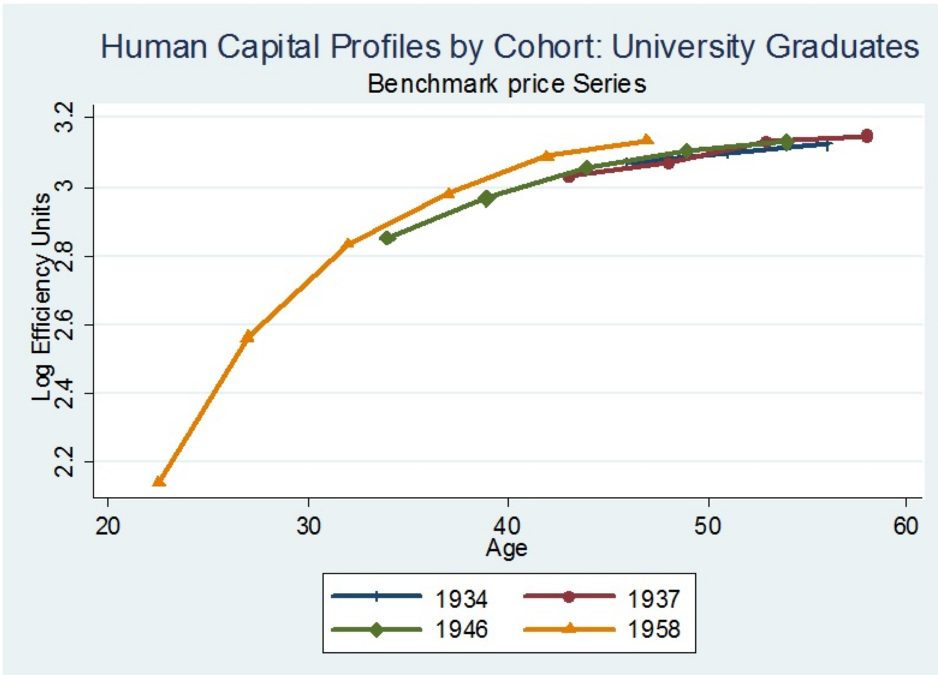


Figure 11: Life-cycle Efficiency Units Profiles: Canadian Male University Graduates

positive and increasing. In addition, from Figure 9 for the 1949 to the 1958 cohort, the effects due to selection for males are positive, while from 1946 to 1949, and from 1958 to 1961 they are zero. The cohort dummy variables reflect this pattern with relatively large increases between 1949 to 1958. The intercept difference over 15 years from the "worst" post war cohort of 1946 to the "best" cohort of 1961 is 10.8. Of the 1946 birth cohort, 30.47% were college graduates; by the 1961 cohort this had fallen to 24.62%, implying a potentially large selection effect as up to 20% of the worst students are no longer going to college.

For the US male cohorts before 1946, the selection effects imply improved cohorts, but this may be partially offset by the negative effect of moving to earlier human capital production functions. The estimates show this: moving backwards from 1946 the intercepts increase, but by more modest amounts than the increase moving forward. The 1943 and 1958 cohorts have roughly similar fractions going to college and therefore differ mainly because of technological improvement. The magnitude

Dependent Variable: Log Efficiency Units		
Birth Cohort	Cohort Dummy Coefficient	
	United States	Canada
1937	0.0447(*)	.
1940	0.0420(**)	.
1943	0.291(*)	0.0030
1949	-0.0031	-0.0026
1952	0.0178	0.0207(**)
1955	0.0483(**)	0.0337(**)
1958	0.0865(**)	0.0506(**)
1961	0.1076(**)	0.0658(**)
Age	0.0914(**)	0.0815(**)
Age Squared	-0.0009(**)	-0.0008(**)
R^2	0.8866	0.9938
N	144	30
Note: Significance levels at 5% and 1% levels indicated by * and **		

Table 2: Estimated Life-cycle Human Capital Profiles for Males by Cohort: Canada and the US

suggests secular technological improvement at an annual rate of about a third to half a percentage point. This implies that the improvement in the 1958 male cohort over the 1946 cohort is composed of roughly equal contributions from selection effects and technological improvement.[29]

The shorter price series for Canada results in a more limited analysis over the birth cohorts from 1943 to 1961. Nevertheless, the results for these cohorts are again consistent with the BR framework. They show exactly the same pattern of improved cohorts after 1946 when the selection effects implied by Figure 11 reinforce the secular technological improvement in human capital production as was observed for the US. The improvement is, however, more muted for Canada.[30]

The potential magnitudes of the selection effects for the US was assessed in BR from an ex-

[29]As an alternative, the cumulative difference in the profiles (compared to the 1946 profile) over 30-45 was estimated without the quadratic approximation and produced the same pattern.

[30]The results for Canada for cohorts before 1946 are limited to the single 1943 cohort. For the US this has a small positive and significant effect, interpreted in the BR framework as a relative strong selection effect outweighing the negative effect from an older human capital production technology for this cohort. For Canada the point estimate is positive, but the magnitude is very small and insignificantly different from zero. If the secular technological improvement rate from advancing knowledge is the same in the two countries, this implies a weaker selection effect for Canada between the 1946 and 1943 birth cohorts. In fact, inspection of Figure 11 shows a potentially weaker selection effect. For the US, the fraction of university graduates in the birth cohort increases by 12.61% between the 1943 and 1946 birth cohorts (.2831 to .3188). For Canada the increase was only 7.00% (.1858 to .1988).

amination of the distribution of human capital quantities within the 1946 birth cohort which had the largest fraction of the cohort completing college. The average real hourly wage in the FTFY sample for males between 40 and 49 years of age, in this cohort is $16.06. The (negative) difference in the fraction of college graduates in the 1937 and 1946 birth cohorts is about 37%, and between the 1958 and 1946 birth cohorts is about 21%. Assuming a stable correlation of one between ability and education, the potential selection effect can be estimated by comparing the unconditional mean $16.06, with the conditional mean after removing 37% (1937-1946) or 21% (1958-1946). The predicted difference due to selection for the 1958 cohort over the 1946 cohort is 14.60%, and for the 1937 cohort is 25.81%. Given the assumption on the correlation these are upper bounds. In Table 2 the human capital of the 1958 US birth cohort is 8.65% above the 1946 birth cohort, which includes both selection and technological improvement effects. Attributing one half of this to selection is quite consistent with a positive correlation between ability and education of much less than one.

The potential magnitude of the selection effects for Canada are assessed in a similar way. The results show very similar magnitudes for any given percentage changes from the 1946 birth cohort fraction university. The percentage changes from the 1949 cohort to the 1961 cohort for Canada and the US are declines of 16.87% for the US and 14.42% for Canada. The decline in the US is larger. This produces a larger increase in the potential per capita quantity increase in the US. Using the actual percentage changes in real hourly wages at the 16.87% and 14.42% cutoffs, the potential quantity increase is 22% larger for the US (12.19 vs 10.01). This is consistent with the more muted increase in the intercepts for the post war cohorts in Canada compared to the US. The actual quality increase also depends on the correlation between ability and completed education. Evidence from Belley, Frenette and Lochner (2014) shows a stronger correlation for the US, controlling for parental income, between ability and post-secondary attendance. However, they are much closer for attendance at a 4 year institution.[31]

Overall, the life-cycle evidence for males in Canada is consistent with the same factors driving cohort effects of similar magnitudes in both countries due to similar technological improvement in human capital production and similar selection effects as the fraction of birth cohorts with a university degree peaked around 1946 and then declined substantially in both countries. In particular, at the university level the evidence is consistent with similar rates of technological improvement.

[31] The picture is complicated by the interaction with parental income differing across the two countries.

6 Cross Country Comparison of the Path of Wages and Efficiency Units by Age and Education Group

The comparative price paths across countries plotted in Figure 4 showed two main differences: (1) the price for university (college) graduates fell much more sharply for Canada, and (2) the price for high school dropouts in the U.S. fell strongly from 1980 to 2000, but not in Canada.[32] The effect on inequality differences via the college wage premium for younger workers was investigated in Section 4. In this section we focus on the difference for the lower education groups, especially the high school dropouts.

The pattern of wages and per worker efficiency units supplied by males for all four human capital types and for young and older workers are presented in Tables 3 and 4. Table 3 presents estimates of wages for the median worker by age and skill type for the period of consistent education coding in the Canadian Census, 1980-2000. Two important features stand out. First, university graduates do much better in the US. In Canada, both young and old university graduates experience a substantial decline in median wages over the 1980-2000 period. By contrast, for the US there is relatively little change except for the 7.66% increase for the young group. Second, for some college, high school graduates and dropouts in both countries there are large declines in median wages that are often very similar across countries, but older workers in Canada for all three below university groups have much less of a decline.[33]

Table 4 reports the time path for efficiency units for the median worker in the same four education groups by age for both countries implied by the price series in Figures 1 and 3 and the median wages in Table 3. Efficiency units for young university graduates increase by similar amounts in both countries. Thus, in terms of the productivity of young Canadian university graduates, as measured by their efficiency units, there is no substantial decline relative to the US. In terms of median wages, young university graduates in Canada suffer a decline in median wages compared to increased median wages for their US counterparts because of the larger price decline that they face for university level human capital in Canada that is not offset by their similarly increased efficiency units.

[32] The some college group and the high school graduates groups showed similar paths, though the Canadian high school graduate price is relatively low during the Canadian recession of the early 2000s.

[33] Note that the Canadian dropouts at both ages are much closer in earnings to high school graduates than in the US: young dropout earnings are about 93% of the high school graduates earnings using the 1981-2001 census education codes (about 88% using the 2006 codes) compared to only about 78% in the US. For the old it is about 86-90% in Canada compared to about 75% in the US.

	Dropouts		High School		Some College		University	
	Canada	US	Canada	US	Canada	US	Canada	US
				Younger (26-30)				
1980	10.74	6.82	11.51	8.75	12.32	8.98	13.42	9.85
1985	10.09	5.81	11.04	7.95	11.48	8.86	13.16	10.58
1990	9.36	5.16	10.33	7.17	11.00	8.09	12.77	9.81
1995	8.26	4.73	9.47	6.56	10.10	7.10	11.73	9.46
2000	8.62	5.08	9.10	6.98	10.21	8.12	12.71	10.61
% Change 1980-2000	-19.75	-25.47	-20.93	-20.25	-17.11	-9.54	-5.29	7.66
				Older (46-60)				
1980	11.93	8.75	13.90	11.67	14.53	12.32	20.85	15.70
1985	11.82	8.04	13.74	11.17	14.40	12.72	19.87	16.09
1990	11.42	7.36	13.49	10.30	14.35	11.77	19.51	15.65
1995	11.29	6.31	12.84	9.46	14.29	11.04	19.05	14.91
2000	11.36	6.42	12.54	9.31	14.36	10.89	18.67	15.36
% Change 1980-2000	-4.78	-26.63	-9.74	-20.25	-1.19	-11.64	-10.44	-2.16

Table 3: Median Wages for Males by Age and Skill Type

Older male university graduates in both countries show efficiency units increases, somewhat larger for Canada. In the US there is a very small decline in median wages while for Canada the decline is larger. For the US the wage decline is small because the price decline was relatively small, requiring only a relatively small increase in efficiency units to largely offset it. For Canada the price decline was large, and the efficiency units increase was not enough to offset it. The lower wages are again a consequence of the larger price decline for university level human capital in Canada.

For the younger workers efficiency units in the non-university groups generally decline. The Canadian dropouts and some college do worse relative to the US, but Canadian high school graduates do better relative to the US. The most notable cross country difference is for older workers. For all groups in the US except university graduates the efficiency units for older workers show almost the same pattern as for the younger group. Dropouts and high school graduates show large declines and some college is stable. However, for Canada the older workers do much better than the young for all non-university education groups. For dropouts efficiency units are roughly constant, while they increase substantially for both high school graduates and some college. The age differences are very marked. For example, for dropouts the young group has a decrease of 14%, compared to and

	Dropouts		High School		Some College		University	
	Canada	US	Canada	US	Canada	US	Canada	US
				Younger (26-30)				
1980	10.74	6.82	11.51	8.75	12.32	8.98	13.42	9.85
1985	10.45	5.98	11.44	8.18	12.00	8.76	13.94	10.45
1990	9.92	5.78	11.19	7.92	11.76	8.22	14.14	10.17
1995	9.00	5.48	11.06	7.80	11.42	7.79	13.78	10.10
2000	9.23	6.07	10.89	7.94	11.64	8.88	15.28	11.01
% Change 1980-2000	-14.02	-10.90	-5.40	-9.31	-5.48	-1.07	13.83	11.70
				Older (46-60)				
1980	11.93	8.75	13.90	11.67	14.53	12.32	20.85	15.70
1985	12.25	8.28	14.24	11.51	15.06	12.58	21.05	15.88
1990	12.11	8.24	14.61	11.37	15.33	11.96	21.60	16.24
1995	12.32	7.31	15.00	11.24	16.16	12.12	22.40	15.92
2000	12.17	7.68	15.01	10.58	16.37	11.91	22.44	15.93
% Change 1980-2000	2.02	-12.28	7.97	-9.31	12.68	-3.36	7.64	1.51

Table 4: Median Efficiency Units for Males by Age and Skill Type

increase of 2% for the older group; and for high school graduates while efficiency units fall by 5% for the young group, they increase by 8% for the older group.

The pattern of efficiency units for the older non-university groups in Canada is something of a puzzle. The cohort pattern of completed education (Figure 8) suggests that selection effects are more likely to have decreased efficiency units for these groups. This raises the possibility that institutional differences across countries, in particular the much larger presence of unions and the public sector in Canada may have resulted in the downward wage adjustment for the non-university groups following SBTC happening more for the younger workers with older workers partially protected by less flexible union and public sector contracts. If this occurs, and influences the flat spot estimates which come from the older workers, then the estimated price series for the non-university groups experiencing decreased demand will be upward biased.

INCOMPLETE - IS THERE A DIFFERENT PRICE IN CANADA FOR OLDER WORKERS?

The analysis is extended to the later period using the LFS for Canada and the MORG for the U.S. TO BE WRITTEN UP

7 Human Capital and Growth in Canada and the US

Within the heterogeneous human capital framework of the previous sections, overall growth in human capital depends on per capita growth for each of the four human capital types through cohort effects estimated in the previous section, on education choices that determine the fraction of the four human capital types, and on growth in the working population. However, the heterogeneous human capital framework is not particularly convenient for aggregate growth studies which tend to use a single measure for the labor input. A homogeneous human capital model has great benefits as the conceptual basis for defining an aggregate labor input and corresponding aggregate wage. The single price feature of the model provides an elegant solution to the definition of the aggregate wage: the price of an efficiency unit, λ, of homogeneous human capital. The single type feature provides a similarly elegant solution to defining the aggregate labor input: the quantity of efficiency units, E. The high correlation exhibited by the price series for both countries documented in Figures 1 (US) and 3 (Canada) implies that for aggregate level analysis the homogeneous price assumption could be used as a reasonable approximation for aggregate analysis. With homogeneous human capital a total efficiency units series, E_t, can be calculated simply by dividing total wage payments, W_t, by the (single) price series, λ_t.[34]

In this section aggregate efficiency units series for each country using single price series derived by pooling the highly correlated series in Figure 1 (US) and Figure 3 (Canada) are compared with more conventional simple aggregate hours or composition adjusted aggregate hours measures for each country. The estimates of per capita human capital quantities for the US in BR, and similar results for Canada in Table 2 above show substantial cohort effects for the university group, through selection and technological improvement in human capital production, on median efficiency units within age (experience) and education groups. As reported in BR, this results in substantial under-estimation of the growth in the true labor input for the US over 1975-2000, and hence substantial over-estimation of the growth in MFP over the same period, relative to those obtained using standard composition adjusted input measures. It is shown below that this is also the case for Canada.

[34] The issue is quite different if human capital is heterogeneous. If human capital is heterogeneous and the types are observationally identifiable by, say, education level, there is little to be gained by arbitrarily aggregating the different types. The production function could simply be modelled with all of the different human capital types. A recent example of this is Johnson and Keane (2008) who estimate a model with 160 different types of human capital.

7.1 Composition Adjusted Hours

Most standard aggregate labor input measures are some form of composition adjusted hours. The BLS provides the main official composition adjusted series for the US as part of its Multi-factor Productivity (MFP) Program. This measure is used in the construction of the BLS MFP index. The BLS measure is described in detail in the BLS Handbook of Methods (1997), and in BLS Bulletin 2426 (1993), which reported the first estimates. It is based on a Tornqvist chained index of weighted hours of workers classified by skill and demographic characteristics.[35]

Other measures of aggregate input, focusing on composition adjustment, have been constructed in the business cycle literature and the macroeconomics literature more generally. Examples include Hansen (1993) and Kydland and Prescott (1993) for a single aggregate, and Katz and Murphy (1992) and Krusell et.al. (2000) for aggregates by skill group. These series are all efficiency units based, either for the economy as a whole or within skill group. They all use a composition adjustment approach, and they produce very similar estimates to the BLS estimates, to which they are closely related.

Statistics Canada takes a similar position to the BLS in recognizing the need to adjust the aggregate hours measures for composition changes, especially regarding skill levels. The current methods make use of a very similar chaining technique to that used by the BLS. The Canadian procedure uses the Fisher ideal index rather than the Tornqvist index. However, these methods produce almost identical estimates. As of 2001, Canada used a two stage approach, first constructing aggregate hours measures at the industry level, and then aggregating the hours growth rates at the industry level using weights based on composition shares. However, an approach similar to that of Jorgenson and the BLS that incorporates composition adjustment at an earlier stage has also been used.[37] Estimates from this approach are presented in Gu *et al.* (2002).

[35] Prior to the development of the BLS measure, a number of authors had developed and published composition adjusted aggregate hours series. See, for example, Chinloy (1980), Denison (1985), and Jorgenson, Gollop and Fraumeni (1987). The most well known current version of these is the Jorgenson series for the U.S. private economy, 1977-2000.[36] When the Jorgenson series is scaled to the BLS series in 1977, the two labor input series look almost the same. See BR for more details.

[37] See Statistics Canada (2001), Appendix 1.

7.2 Aggregate Labor Input: Comparison of the Alternative Measures

Table 5 reports the growth rates from 1980 to 2000 for the three alternative aggregate labor input measure for the two countries for paid workers, age 20-64.[38] The BLS-style (Tornqvist) composition adjusted series was calculated as described in BR, using 120 groups classified by education, age and sex for paid workers aged 20-64.[39] Total unadjusted hours grow faster in the United States (47%)

	Canada			United States		
	All	Males	Females	All	Males	Females
Efficiency Units	0.6603	0.4464	1.1889	0.8548	0.6658	1.3029
Hours	0.3987	0.2458	0.6688	0.4699	0.3573	0.6377
BLS	0.5640	.	.	0.6402	.	.
BLS(A)	.	0.3626	1.0620	.	0.4732	1.0365
BLS(B)	.	0.3968	0.9618	.	0.5371	0.8677

Table 5: Growth Rates of Alternative Labor Input Series

than in Canada (40%), due to the faster growth of hours for US males. The growth in female hours is slightly higher in Canada (67% vs. 64%) but male hours grow much slower in Canada (25% vs. 36%). The growth in hours is substantially less than the growth in composition adjusted hours in both countries. In addition, for both countries the growth in composition adjusted hours is itself substantially less than the growth in efficiency units. Composition adjusted hours grow faster than the unadjusted series because of the increased education level in the population. Efficiency units grow faster than composition adjusted hours because the composition adjustment ignores the cohort effects.

The magnitudes of the differences between the measures are large for both countries. For Canada, the growth rate in efficiency units was 66.03%, compared to 56.40% growth in composition adjusted hours and 39.87% growth in aggregate hours. For the US efficiency units grew by 85.48%, compared to 46.99% for aggregate hours and 64.02% for composition adjusted hours. For both countries the composition adjustment rate was about the same. For Canada, the composition adjustment produces a labor input growth that is about 40% higher than the unadjusted hours growth. However, the growth in efficiency units was 65.6% higher. The standard composition adjustment to hours is

[38] Comparison of the three measures have simple interpretation within the homogeneous human capital framework derived in BR.

[39] The March supplement weights were used for all the total estimates, for the US. For Canada the RDC census file weights were used.

therefore only about 60% of the full adjustment to aggregate hours that is necessary to estimate labor input growth between 1980 and 2000 for Canada. Similarly, for the US, the standard composition adjustment to hours is only about 45% of the full adjustment.

Table 5 also reports the growth rates of alternative labor input measures by sex. The price series are all estimated using wage data from males. The significant variation in life-cycle and secular female labor force participation, as well as discrimination, introduces major difficulties in estimating the price series from female wage data.[40] The BLS method for total hours uses compensation shares to weight the growth of each type of hours, including male versus female. The logic of this weighting suggests that to get separate totals for males and females, the total labor input estimate should be split between males and females according to the compensation shares in the year, assuming no discrimination. The results for this method are denoted BLS (A). An alternative is to apply the BLS method separately to estimate compensation share weighted male hours growth and compensation share weighted female hours growth. The results in this case are denoted BLS (B).

The use of compensation shares in the BLS method implicitly assumes that the wage rate for females reflects the true marginal product, i.e. there is no discrimination. The estimates of total efficiency units in Table 5 are also based on this assumption. If discrimination creates a significant difference between the wage and the marginal product of female labor, without adjustment the total efficiency units series would be underestimated, and the degree of underestimation would vary over time as the degree of discrimination varied. In a standard employer discrimination model, where efficiency units of males and females are identical, but females receive a lower rental rate due to discrimination, the true efficiency series should be calculated separately for males and females. For males it is calculated as before by dividing total wage payments by the estimated price; for females, the total wage payments first have to be scaled up according to the amount of the discrimination. If, for example, discrimination against females was declining over the period, the growth in efficiency units for females would be over-estimated.[41]

Human capital theory predicts that the increased labor market attachment of females in both countries has increased female human capital investment. The substantial literature on female wage differentials has documented this increase, which has taken many forms, including more market oriented human capital investments for females at university. This increase has resulted in an

[40] See Bowlus and Robinson (2016) for more discussion of this issue.
[41] See Bowlus and Robinson (2016).

increase in the total labor input of females by all measures, including total hours. Bowlus and Robinson (2016) provide estimates of increased efficiency units supplied by females within education and experience cells for the U.S. using both the wage-based methods employed in BR, but also using job-skills data.

In Canada, total hours for female paid workers increased by 66.88% from 1980 to 2000, which is more than double the growth in male hours of 24.58%. The growth in efficiency units for females, however, is particularly pronounced. From 1980 to 2000 the growth in efficiency units for females is 118.89%, which is almost double the growth in hours. In contrast, much smaller rates of growth are estimated using the BLS style measures: 106.20% for BLS (A) and 96.18% for BLS (B). The same pattern is observed in the US. Efficiency units grow by 130.29% but the BLS measures show much smaller growth, with 103.65% for BLS(A) and 86.77% for BLS(B).

Table 5 also reports the estimated growth rates using fixed weight methods. BR constructed efficiency unit aggregates by skill and in total using a method analogous to Krusell *et al.* (2000) and Kydland and Prescott (1993). These fixed weight methods are similar to the BLS and Jorgenson methods in that they aggregate the hours of different types of workers using average wages as weights, classifying the different types of workers according to age, sex and education. The composition adjustment applied to aggregate hours implied by the fixed weight approach is almost identical to the estimates obtained for BLS style methods. Thus, the fixed weight method has the same degree of underestimation of the increase in the labor input as the BLS method. Fixed weight methods, by construction, do not permit total efficiency units of labor to increase if the demographic composition does not change, except through hours. This has little effect for cyclical analysis, but for longer term secular growth or cross country comparisons, it is potentially extremely important. One important consequence is the potential for serious overestimation of MFP and underestimation of the role of human capital in growth.

INCOMPLETE - RESULTS TO FOLLOW FOR POST 2000 DATA FOR BOTH COUNTRIES

7.3 Consequences for Multi-factor Productivity

A major motivation for the construction of quality adjusted labor input series like those of Jorgenson, the BLS and Statistics Canada is that the use of unadjusted hours results in a substantial bias in the estimation of MFP. MFP is defined in a similar way in the United States and Canada. Since changes in MFP are defined as the residual change in output that cannot be accounted for by the changes in the inputs, the estimates of these changes are sensitive to the estimates of the changes in the inputs. For the U.S. for the period 1975 to 2001, the growth in hours underestimates the growth in efficiency units of paid private workers by 62.04 percentage points. Since the share of labor in total costs is roughly two thirds,[42] this implies that MFP would be overestimated by about 40 percentage points if unadjusted hours were used. Using composition adjusted hours makes a substantial correction to this, but still underestimates the growth in efficiency units by 36.46 percentage points. Hence, this BLS type adjustment still implies an overestimate of the growth of MFP of 24 percentage points. The actual BLS estimate of MFP growth in the private business sector between 1975 and 2001 is 23.76 percent.[43] The results therefore suggest that all of this could be due to an undercount of the increase in the labor input. In fact, as noted earlier, our efficiency units estimate for females is probably too high which exaggerates the underestimate of efficiency units and the overestimate of MFP . For example, the overestimate of MFP would be reduced to below 20 percentage points if discrimination against females over the period declined in the range of 10-12 percentage points.

Even with a reasonable adjustment for the estimated increase in female efficiency units, these results for MFP indicate that much of the source of improvement over time in standard of living is due to technological improvements in the production of human capital or increased human capital investment. Individuals exposed to more recent education and on-the-job training systems receive more value added to their human capital. This is not captured by composition adjustment. Similarly, composition adjustment cannot capture the increased human capital for females that would be expected from a large increase in lifetime participation and hours for females.

For Canada, for the 1980 to 2000 period, efficiency units for paid workers grew by 26 percentage points more than unadjusted hours and 10 percentage points more than composition adjusted hours. (The differences for the United States for the same population and period are 38 and 21.) The labor share of total costs in Canada is similar to that in the United States at about two thirds. This implies an over-estimate of MFP growth by 7 percentage points over the 1980 to 2000 period. This is one half of conventional estimates of MFP growth for the period, suggesting again that a substantial part of estimated growth is actually due to an undercount of the increase in the labor input.

These results for multi-factor productivity indicate that much of the source of improvement over time in standard of living is due to technological improvements in the production of human capital.

[42]The BLS estimates for labor share in total cost are 0.678 in 1975 and 0.686 in 2001.
[43]See Table PB4a in mfp2ddod.txt at the BLS Multi-factor Productivity website.

Individuals exposed to more recent education and on-the-job training systems receive more value added to their human capital. This is not adequately captured by composition adjustment that focuses on increasing shares of, for example, college educated workers, but not on whether a given observed education level, such as college, for the 1946 birth cohort corresponds to the same level of human capital accumulation for an otherwise identical individual from the 1966 birth cohort.

The results for both countries show large effects on the estimates of MFP when quality variation across time in the labor input is controlled for. MFP no longer appears to be the main driver of within country changes in standard of living. Rather, the main driver appears to be increases in per capita human capital, adjusted for quality. There is a large and increasing literature on incorporating quality adjustments to human capital measures for international comparisons and international growth studies. In a recent paper that re-opens the question on the sources of cross country variation in wealth, Manuelli and Seshadri (2014) argue that quality differences in human capital, that are not captured by observed measures that are typically used in composition adjustments, substantially reduces the role of MFP differences in explaining cross country differences in wealth. Their estimates show very little cross country difference in MFP when the quality of human capital is taken into account. TFP in the poorest countries is not much smaller than that of the United States at around 73% of the United States figure. By contrast, studies that do not take into account human capital quality find rates for the poorest countries at only 20% of the United States value. This mirrors the findings in this section that there is much less difference across time within countries in MFP when the quality of human capital is taken into account.

8 Conclusions

INCOMPLETE

Canada and the US showed different paths in wages, skill premiums, and inequality over the last three or four decades. The evidence presented in this paper suggests that a major reason for these different paths was a different evolution of human capital prices in the two countries over the period, especially the relative decline in the price for university level human capital in Canada compared to the US. Analysis of this difference in price paths within the framework of the canonical model suggests that one reason for the depressed the skill price in Canada relative to the US is the difference in the “immigration shocks” in the two countries analyzed in Aydemir and Borjas (2007).

A notable feature of the cross country comparison in median wages is a clear difference by age for the less skilled (below university) workers. In the US, less skilled older workers experienced the same declines as younger workers, but not in Canada, where older workers avoided the large declines experienced by younger workers. Using the price series estimates, this results in an increase in efficiency units for older workers in Canada below university level that does not occur for the US. The different pattern of efficiency units for the older non-university groups in Canada may be influenced by institutional differences across countries, in particular the much larger presence of unions and the public sector partially protecting older workers from downward wage adjustment. INCOMPLETE

A decomposition of the path of the university premium shows that in both countries the increase in the premium was mainly due to a relative per worker quantity increase in the human capital of university graduates, not a relative price increase. For Canada almost all the increase is due to relative quantity changes, while in the US it is about two thirds. In both countries the per worker relative quantity changes in human capital reflect cohort effects due to selection and technological progress in human capital production, especially for the university educated workers. Estimates of these effects in a life-cycle framework show a common pattern across countries in the relation between the human capital profiles of university graduates from successive birth cohorts. Both countries show the pattern that would be expected from a combination of secular technological improvement in human capital production and selection effects implied by the changing fraction of university graduates by birth cohort. While the qualitative patterns in the path of the fraction of university graduates by birth cohort are the same across countries, there are some differences in the magnitudes. These differences are consistent with different magnitudes for the selection effects in Canada implied by the differences across countries in the magnitude of the changes in the fraction of university graduates by birth cohort.

The estimated price series for the two countries allow the estimation of the growth in the true labor input in each country, taking into account changes in efficiency units within age, sex and education groups that cannot be captured in standard composition adjusted hours measures. The omission of these effects in standard measures leads to a substantial under-estimation in the growth of the true labor input in both countries. The difference is mainly due to technological improvement in human capital production, broadly interpreted, and the increased human capital investment of females from more recent cohorts implied by their higher levels of labor force participation. For both countries, adjusting the labor input for quality changes by using the estimated quantity series dramatically reduces the contribution of MFP growth in standard of living growth. This parallels the recent result in Manuelli and Seshadri (2014) that quality adjustment to international comparisons of human capital comes close to eliminating MFP differences as the source of cross country differences in wealth.

References

[1] Daron Acemoglu and David Autor. Skills, Tasks and Technologies: Implications for Employment and Earnings. In Orley C. Ashenfelter and David Card, editors, *Handbook of Labor Economics*. North Holland, 2011.

[2] David H. Autor, Lawrence F. Katz, and Melissa S. Kearney. Trends in U.S. Wage Inequality: Revising the Revisionists. *Review of Economics and Statistics*, 90:300–323, 2008.

[3] Gary S. Becker. *Human Capital*. National Bureau of Economic Research, New York, 1964.

[4] Philippe Belley, Marc Frenette, and Lance Lochner. Post-Secondary Attendance by Parental Income in the U.S. and Canada: Do Financial Aid Policies Explain the Differences. *Canadian Journal of Economics*, 47:664–696, 2014.

[5] Yoram Ben-Porath. The production of Human Capital and the Lifecycle of Earnings. *Journal of Political Economy*, 75:352–365, 1967.

[6] Audra Bowlus, Eda Bozkurt, Lance Lochner, and Chris Robinson. Wages and Employment: The Canonical Model Revisited. Working Paper, 2016.

[7] Audra Bowlus and Chris Robinson. The Evolution of the Human Capital of Women. Working Paper, 2016.

[8] Audra J. Bowlus, Haoming Liu, and Chris Robinson. Business Cycle Models, Aggregation and Real Wage Cyclicality. *Journal of Labor Economics*, 20:308–335, 2002.

[9] Audra J. Bowlus and Chris Robinson. Human Capital Prices, Productivity and Growth. *American Economic Review*, 102.

[10] Audra J. Bowlus and Chris Robinson. Human Capital Prices, Productivity and Growth. University of Western Ontario, CIBC Working paper No. 2008-5, 2008.

[11] John Burbidge, Kirk Collins, James B. Davies, and Lonnie Magee. Effective Tax and Subsidy Rates on Human Capital in Canada. *Canadian Journal of Economics*, 45:189–219, 2012.

[12] Bureau of Labor Statistics, U.S. Department of Labor. *Labor Composition and U.S. Productivity Growth, 1948-90*, Bulletin 2426, 1993.

[13] Bureau of Labor Statistics, U.S. Department of Labor. *Handbook of Methods*, 1997.

[14] David Card and Thomas Lemieux. Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort Based Analysis. *Quarterly Journal of Economics*, CXVI:705–746, 2001.

[15] Pedro Carneiro and Sokbae Lee. Trends in Quality Adjusted Skill Premia in the United States: 1960-2000. *American Economic Review*, 101.

[16] Peter Chinloy. Sources of Quality Change in Labor Input. *American Economic Review*, 70:108–19, 1980.

[17] Serge Coulombe, Jean-Francois Tremblay, and Sylvie Marchand. *Literacy Scores, Human Capital and Growth across Fourteen OECD Countries*. Statistics Canada, 2004. Catalogue No. 89-552-MIE.

[18] Edward Denison. *Trends in American Economic Growth, 1929-1982*. Brookings Institution, Washington, DC, 1985.

[19] Claudia Goldin and Lawrence F. Katz. Long-Run Changes in the Wage Structure: Narrowing, Widening, Polarizing. *Brookings Papers on Economic Activity*, pages 135–165, 2007.

[20] David A. Green and W. Craig Riddell. Ageing and Literacy Skills: Evidence from Canada, Norway and the United States. *Labour Economics*, 22:16–29, 2013.

[21] David A. Green and Benjamin M. Sand. Has the Canadian Labour Market Polarized? *Canadian Journal of Economics*, 48.

[22] Gary D. Hansen. The Cyclical and Secular Behavior of the Labor Input: Comparing Efficiency Units and Hours Worked. *Journal of Applied Econometrics*, 8:71–80, 1993.

[23] Eric A. Hanushek and Dongwook Kim. Schooling, Labor Force Quality, and Economic Growth. NBER Working Paper No. 5399, 1995.

[24] Eric A. Hanushek and Dennis D. Kimko. Schooling, Labor Force Quality, and the Growth of Nations. *American Economic Review*, 90:1184–1208, 2000.

[25] James J. Heckman, Lance Lochner, and Christopher Taber. Explaining Rising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of labor Earnings with Heterogeneous Agents. *Review of Economic Dynamics*, 1:1–58, 1998.

[26] Lutz Hendricks and Todd Schoellman. Student Abilities During the Expansion of US Education. *Journal of Monetary Economics*, 63:19–36, 2014.

[27] Matthew Johnson and Michael P. Keane. A Dynamic Equilibrium Model of the U.S. Wage Structure, 1968-1996. mimeo, 2008.

[28] Dale W. Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni. *Productivity and U.S. Economic Growth*. Harvard University Press, Cambridge, MA, 1987.

[29] Lawrence Katz and Kevin Murphy. Changes in Relative wages, 1963-1987: Supply and Demand factors. *Quarterly Journal of Economics*, 107:35–78, 1992.

[30] Finn E. Kydland and Edward C. Prescott. Cyclical Movements of the Labor Input and Its Implicit Real Wage. *Federal Reserve Bank of Cleveland Economic Review*, 29:12–23, 1993.

[31] Rodolfo E. Manuelli and Ananth Seshadri. Human Capital and the Wealth of Nations. *American Economic Review*, 104:2726–762, 2014.

[32] Jacob Mincer. *Schooling, Experience and Earnings*. National Bureau of Economic Research, Columbia University Press, New York, 1974.

[33] Organization of Economic Cooperation and Development, OECD. *Education at a Glance - OECD Indicators*, 1998.

[34] Jan Tinbergen. Substitution of Graduate by Other Labor. *Kyklos*, 27:217–226, 1974.

[35] Yoram Weiss and Lee Lillard. Experience, Vintage and Time Effects in the Growth of Earnings: American Scientists, 1960-1970. *Journal of Political Economy*, 86:427–447, 1978.