Human Capital, Productivity and Growth

by

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Abstract

In this paper new estimates of human capital prices and quantities, taking into account technological change in human capital production and endogenous education choice, are presented for both Canada and the United States. The implications of the estimates for the sources of growth are examined. The most striking result is that adjusting the labour input for quality increases reduces the contribution of MFP growth in standard of living growth to zero. The largest part of this quality increase is not due to composition changes but instead to technological change in human capital production. Since most attempts at adjusting the labour input for quality changes only deal with composition, they cannot capture a large part of the quality change. The results suggest that technological improvement in human capital production could be the major source of standard of living growth in the last few decades.

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1 Introduction

The flow from human capital is by far the most important input in the world economy. The estimated share of labour in the United States and most of the OECD countries, for example, is about two thirds. Human capital theory has been the basis of a huge literature studying the determination of earnings since the seminal work of Becker (1964), Ben Porath (1967), Mincer (1974) and many others.[1] There is by now quite general agreement that human capital plays a significant role in the determination of living standards. However, assessing the contribution of human capital to output, living standards and growth is hampered by serious conceptual and measurement problems, especially for international comparisons and for secular analyses over several decades. In this paper we argue that a major omission in the literature has been to ignore technological change, broadly interpreted, in the human capital production functions that characterize a country's education and on the job-training system. This has resulted in a serious under-estimate of the growth of the labour input when conventional measures are used, and conversely a large over-estimate of the growth of total factor productivity (TFP). Using a new approach that takes technological change into account, we find that growth in the average levels of human capital, not TFP, accounts for the increase in living standards in Canada and the United States since 1975.

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. For example, a common measure of general human capital is years of schooling. Refinements of this take into account work experience - usually in the form of some

[1] See Willis (1986) for a survey.

measure of total accumulated time at work. For international comparisons, often the adopted procedure is to compare the fraction of the relevant populations with various levels of education.[2] At the most basic level, this methodology faces the major problem of aggregating workers of different levels of education. This is sometimes avoided by choosing a measure such as the fraction of the population who have graduated high school (for comparison across developing countries) or the fraction of the population with post-secondary education (for comparison across developed countries). 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 United States 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. For a variety of important contexts, a better measure of human capital is needed. A better measure is also needed to answer some of the most important questions in the current literature on wages, productivity and growth.[3]

Several countries have attempted to get better measures of human capital by refining the construction of their aggregate labor input indices, previously measured by aggregate labor hours, to take into account changes in the composition of the labor force. The rapidly increasing average education levels in the workforce was a major reason for this initiative. However, these measures do not take into account endogenous schooling decisions, or more importantly, technological

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[2]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.

[3]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 labour 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 that occur if human capital is heterogeneous.

change in the production function for human capital itself. As a result, they fall a long way short of measuring the actual increase in the labour input. Our estimates show a substantial increase in human capital due to technological change that the conventional composition adjusted measures cannot capture.

Measuring technological change in human capital production functions presents special problems because of the difficulty of measuring the output. In Bowlus and Robinson (2004), a technological improvement is measured by the estimated increase in human capital quantity associated with any observed level of education or job market experience. The interpretation of technological change is a broad one. In particular, this technological change should not be narrowly interpreted as the technological means of conveying a given set of information from a teacher to a student. Obviously, the information conveyed changes over time. Presumably the amount of "physics task" that a physics graduate from a given point in the initial human capital endowment distribution in the 1966 birth cohort can do is much larger than that of the graduate from the 1946 cohort from the same point in the distribution mainly because of the advanced physics information conveyed rather than a better technology of conveying the same instruction that the 1946 birth cohort individual received.

The data used for the paper come from the United States and Canada. The data from these countries are broadly comparable. The two countries are quite similar in many ways, but for the issues raised in this paper, they provide an excellent contrast for comparison purposes. In particular, the differential between average wages of skilled workers and unskilled workers has taken a quite different path in the two countries in the last few decades. In addition, there has been a widening gap in the standard of living between the countries.

Section 2 discusses identification issues in homogeneous and heterogeneous human capital models, while Section 3 describes and compares the data sources for the two countries. The estimated price series for the United States and Canada are reported in Section 4. The labour input price declined substantially in both countries until the early 1990s. This decline is much larger than is apparent in composition adjusted aggregate wage series. In the recovery from the early 1990's recession, the series for the two countries diverge. The price in the United States began a substantial upward trend, while in Canada the price decline continued. By 2000, this divergence produced a gap of 13 percentage points in the labour input price in the two countries. Over the same period, the average Canadian worker suffered a substantial loss in standard of living relative to the average United States worker, in large part due to receiving a lower price for his/her human capital relative to United States workers.

Section 5 presents estimates of the quantity of human capital in Canada and the United States. The series show faster growth in efficiency units for the United States. At the per worker level the difference in growth rates in efficiency units for the 1980-2000 period was relatively modest. In the United States, per worker efficiency units grew by 37.42% compared to 31.58% in Canada. This contributed about one third to the 18% relative loss in standard of living for the average Canadian worker, while the remaining two thirds was due to the declining price of human capital in Canada compared to the United States following the early 1990's recession.

Section 6 compares these labour input estimates with standard composition adjusted aggregate labour input measures, including series calculated by Jorgenson and the Bureau of Labor Statistics (BLS) for the United States and Statistics Canada for Canada. The comparisons show that conventional composition adjusted measures substantially underestimate the labour input. In both countries the composition adjustments result in estimated rates of growth in the labour input in that are 36-40% higher compared to unadjusted hours. However these composition adjustments fall a long way short of the growth in efficiency units. In both countries, the rate of growth of efficiency units is about 40% faster than the rate of growth of composition adjusted hours. In the United States the growth rate of efficiency units is 90.11%, which is ten percentage points higher than Canada's rate of 79.43%. Roughly two thirds of the difference is due to faster growth in hours in the United States and one third to a faster growth in efficiency units per hour. Only a very small part of the difference in efficiency units per hour is due to composition differences. Thus, BLS style comparisons cannot identify the main source of the difference in efficiency units per hour across the two countries.

The substantial underestimate of the aggregate labour input in conventional measures has important implications for TFP or multi-factor productivity (MFP) estimates which use these labour input measures. These are discussed in Section 7. The estimates suggest that most, if not all, of the BLS estimated growth in MFP in the private business sector from 1975 to 2001 is due to the undercount of the increase in the labour input. Similarly, for Canada over the period 1980-2000, the under-estimate of the labour input using standard composition adjusted measures is the source of all the estimated MFP growth for the period. Using the quality adjusted labour input, MFP contributes nothing to changes over the period in living standards in the two countries. This dramatically reduced role for MFP when the quality of human capital is taken into account is also found in a recent study of cross country variation in wealth.[4] Finally, some conclusions and discussion of future work are given in Section 8.

2 Identification Issues: The Price and Quantity of the Human Capital Input

In standard human capital models with competitive firms the hourly wage is the product of a price and a quantity:

$$w_{it} = \lambda_t E_{it} \tag{1}$$

where E_{it} is the amount of human capital supplied to the firm (number of efficiency units) by worker i in time period t, and λ_t is the rental price paid for renting a single unit of human capital (the price of an efficiency unit). The hourly wage is observed, but its two components are not. This is the fundamental under-identification property of human capital models.

[4]See Manuelli and Seshadri (2005).

In a homogeneous human capital model there is a single price, λ, and wages differ across workers in any given time period because of differences in the amount of (homogeneous) human capital they are supplying. Over time a worker's wage could change either because of a change in the quantity of efficiency units he/she supplied, or because of a change in the efficiency units price. Over time, *relative* wages between any two observable "types" of workers reflect only relative changes in quantity supplied by each type since there is a single price. This is the main consequence of the efficiency units approach in a homogeneous human capital model.

In the heterogeneous human capital models, an efficiency units approach is retained within some exogenously defined worker "type" (e.g. college degree) but is abandoned across types.[5] With two worker types (e.g. college and non-college) there are two factors and two prices with wages given as follows (suppressing the subscripts for convenience):

$$w^a = \lambda^a E^a \qquad \text{and} \qquad w^b = \lambda^b E^b$$

where λ^a and λ^b are the prices of efficiency units of type *a* and *b* respectively, and E^a and E^b are the number of efficiency units of type *a* supplied by a type *a* worker, and the number of efficiency units of type *b* supplied by a type *b* worker, respectively. Within type, the wage implications are the same as the homogeneous human capital model. For relative wages across types the implications are potentially different. Since there are now two prices, changes in relative wages between two types reflect changes in relative quantities E^a/E^b and changes in relative prices λ^a/λ^b .

The analysis in this paper uses a homogeneous human capital model in preference to a heterogeneous model. The benefits of a homogeneous human capital model for this type of aggregate level study are many. The simplicity and ease of aggregation are a major advantage for the purposes of comparing human capital stocks across time or countries or assessing the

[5]See, for example, Krusell, *et. al.* (2000).

contribution of human capital to growth. The single price feature is a major advantage in providing an elegant solution to the problem of defining an aggregate wage. The single type feature provides a similarly elegant solution to the problem of defining an aggregate quantity. Homogeneous human capital models are, in fact, implicitly or explicitly used in many aggregate studies, especially those concerned with growth, where a single aggregate labour input is used.

In recent micro level studies, heterogeneous human capital models have been prominent in the debate over skill-biased technological change and rising inequality in the United States. These heterogeneous models have several drawbacks for the type of aggregate analysis conducted in this paper. If human capital is heterogeneous and the types are observationally identifiable by, say, education level, there is in fact little to be gained by arbitrarily aggregating the different types. Indeed, since the types are different factors of production, from a production function point of view the types can no more be sensibly added than adding kilowatts of electricity and hours of “unskilled” labour. There is no common unit for the addition. An aggregate level analysis can be carried out with a heterogeneous model, but without a meaningful aggregate labour input.

One reason for the popularity of heterogeneous human capital models is the apparent inconsistency of the homogeneous model with the evidence in the United States of a rising skill premium. However, evaluating this evidence in light of the fundamental under-identification of human capital models, Bowlus and Robinson (2004) argue that a single price model, based on a homogeneous human capital model amended to take into account education selection and technological change in human capital production functions, is a very good approximation. In fact, this homogeneous model with technological change is consistent with the overall skill premium pattern, including the pattern by cohort within heterogeneous type. The standard heterogeneous model that identifies the skill price ratio by assuming no technological change or selection is consistent with the time path of the observed cross section wage ratio by skill in the

United States, but not with the cohort pattern.[6] Thus, the aggregation advantages of a homogeneous human capital model can be retained without any conflict with the evidence on skill premia.

The identification of the prices and quantities of human capital is a difficult problem in both homogeneous and heterogeneous human capital models. In heterogeneous human capital models it is implicitly solved by assuming that the quantities of human capital associated with any observed education level at any point in time are the same. This permits the identification of the skill price ratio from the wage ratio. It also permits the identification of (changes in) the quantities from the hours supplied at any observed education level. However, as noted earlier, this rules out both education selection and technological change in human capital production. Since major quality improvements due to technological change have been found for capital inputs such as computers, it is surprising that it is generally ruled out for the labour input. In the computer case, estimates of the quality improvements are relatively easy to obtain since the efficiency units in computers are directly measurable. Suppose instead that they were not in fact directly measurable, and that only price information, etc., was available. If the standard identifying assumption used in the heterogeneous human capital model was applied to the computer input, using the cost of the inputs that went into its manufacture, the price paid for it, or the size of the "box", it would clearly be a very bad assumption.

Bowlus and Robinson (2004) consider two identification methods: the "standard unit" method, which can be applied under certain conditions to identify prices and quantities over time within a homogeneous human capital model, and the "flat spot" method which can be used with either homogeneous or heterogeneous models. In principle, the simplest approach to identification in a homogeneous human capital model is to find an observable "standard" unit of human capital that is the same across time. In that case, observing the wage paid for a standard unit at different points in time identifies the price change. Given the homogeneous human capital

[6] See Card and Lemieux (2001) for the cohort patterns in the United States, and the difficulties the heterogeneous model faces in explaining the Canadian data.

assumption, this price can then be applied to any worker's wage to infer the quantity of human capital. This is similar to the notion of finding a time invariant common unit for computers. The solution in the computer case was to assume that the common unit that represents the factor provided by all computers is calculations per second. That is, calculations per second are the efficiency units. The relevant price is the price of a "standard" computer defined as having a given number of calculations per second.

Given the assumption of the common unit, the identification problem in the computer case is made very simple by the fact that computations per second can be observed so it is not necessary to actually observe "standard" computers over time to identify the relevant price. In the human capital case it is necessary to observe a standard unit over time because efficiency units are not directly observed. In principle, an ideal standard unit would be a group of workers, drawn from the same region of the initial human capital endowment distribution in each period, who made no further investment in human capital. In practice, a group with the lowest exposure to human capital production functions, and the least addition to their initial human capital endowment has to be used.

The flat spot method, proposed in Hechman, Lochner and Taber (1998), is based on the fact that most optimal human capital investment models have the feature that at some point in the working life-cycle, optimal net investment is zero. If there is a period of years in which this occurs, the human capital of a given cohort over those years is constant by assumption. That is, there is a flat spot in the human capital life-cycle profile. Observing the changes in average wages for the cohort over the flat spot, therefore, identifies the human capital price changes. Provided such flat spots exist, this method can be used with any skill group to identify skill prices.

3. Data Sources

The data source for the United States is the March Current Population Surveys (MCPS) for 1976 to 2002. The earnings data are earnings from wages and salaries from the calender year preceding the survey, covering 1975-2001. The earnings data were confined to paid employees by restricting the sample to those for whom the class of worker on the longest job in the year preceding the survey was a private or public paid employee. An adjustment was made to correct for top-coding. Paid employees were distinguished according to observed education level. Prior to the survey year 1992, the MCPS education measure was the number of years of schooling completed. After January 1992, actual degrees and diplomas were recorded. This break in the series was examined in detail in Jaeger (1997), using a matched panel of respondents that answered both forms of the education questions. Jaeger derives a recoding scheme to produce approximate consistency in four categories: dropouts, 12th grade, some college and college graduates.

The Canadian data set is derived from the public use samples from the censuses for 1981, 1986, 1991, 1996 and 2001.[7] The census contains measures of total wage and salary earnings and total weeks worked in the previous year, as in the MCPS for the United States. 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, so an hourly wage rate can be constructed. The United States series was constructed using data on paid employees. It is not possible to identify class of worker status on the longest job in the preceding year in the Canadian data. The restriction to paid employees is imposed instead by requiring no self-employed earnings. Given

[7]The closest equivalent repeated cross section data sources for Canada come from the Survey of Consumer Finances (SCF). This survey was held every year 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 serious problems in the Canadian data that do not occur in the MCPS. The most serious problems are the non-contemporaneous measures of hours and earnings and a major break in the education series. The survey measures total earnings from wages and salaries for the preceding year and records the number of weeks worked in the same (preceding) year. However, the measurement of usual hours per week refers to the reference week of the survey, rather than the preceding year. The education questions changed significantly between the 1988 and 1989 earnings years, resulting in a sharp change in the percentage of individuals recorded in post-secondary education. Gu *et. al*. (2002) argue that the census education measures are preferable in this regard to the SCF measures and use the census for the Statistics Canada series on a composition adjusted labour input series for 1961-2000.

the small size of the self-employed population and the relatively small contribution of self-employed earnings to the total earnings of workers in the United States whose longest job was not self-employed, it is assumed that this difference in definition has a negligible effect on differences in mean earnings for paid employees. As for the United States data, an adjustment was made for top-coding, though in the Canadian data the incidence of top-coding is very small.

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: dropouts, high school graduates, some post-secondary, and BA degree or higher.[8] The dropout category presents some problems of comparability. Canada currently has a high fraction of individuals with some post-secondary education obtained outside university. This fraction has changed substantially over time. Since much of this education does not require a high school grade level above 10, let alone high school graduation, it is not clear how it should be treated.[9] The dropout group in the United States has no post-secondary education. The dropout group used

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[8]The census documentation makes it clear, however, that "highest level of schooling" should not be interpreted in a strictly 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. Details of the Canadian categories are given in the Appendix.

[9]It raises the more general problem of formal and informal training after elementary or high school. If a worker, A, with a grade 10 education works for a firm that trains its workers "in-house" is compared to a worker, B, also with a grade 10 education but whose firm trains its workers at an outside operation that may or may not grant a certificate, should worker B be rated as having more education? If the training was the same, the workers would have the same human capital. If this kind of roughly equivalent post-school training increasingly took place outside firms the fraction with post-secondary education would increase without any increase in human capital and the apparent wage gain from the post-secondary education would be zero.

for Canada imposes this requirement; the precise definitions for Canada are given in the Appendix.

4 Estimates of Human Capital Prices for the United States and Canada

This section presents and compares estimates of human capital price series for the United States and Canada based on three alternative methods. The standard unit method is applied to the young dropout group in each country. The flat-spot method is applied to relevant age ranges for the dropout group in each country to estimate price series for the least skilled, and to the group with a BA degree or higher to estimate skilled price series for comparison. Detailed discussion of the computation methods is given in Bowlus and Robinson (2004).

The standard unit approach requires the group corresponding to the standard unit to be drawn from the same region of the initial endowment distribution across cohorts. The choice of standard unit involves a number of tradeoffs, discussed in detail in Bowlus and Robinson (2004). The education level for this group should be the lowest of the categories - the dropouts. The first check on potential biases with the standard unit method is to see if the fraction of dropouts in each birth cohort that supplies the standard unit group across the years of the sample is the same over time. As Figure 1 shows, this is true for the United States; for Canada, however, this fraction declines over time.

The pattern in Figure 1 for both countries is a strong decline until the post-war birth cohorts. At this point, however, the patterns diverge. The relevant cohorts for the price series that can be constructed for Canada, are the 1958 - 1973 birth cohorts. Between the 1958 and 1973 cohorts, there is a drop in the fraction of dropouts in the cohort from 25.17% to 16.97%, representing a decline of about one third. In the United States, by contrast, the fraction over the relevant cohorts, beginning in 1955, is constant. Assuming a positive correlation between schooling level choice and initial human capital endowment, the decline over time in the cohort dropout fraction exerts a downward bias in the estimated price series for Canada based on the standard unit method. The constant fraction of dropouts in the United States across cohorts suggests that this potential bias is not present for the estimated standard unit price series for the United States.

A second check on the validity of the assumptions for the standard unit method is an examination of whether the variance of log wages for the standard unit group is constant over time. Figure 1 shows that for the United States the fraction in the relevant cohorts is the same over time. If this represents the same drawing from the initial endowment distribution, both the mean and variance of efficiency units, or the log of efficiency units, should be the same across cohorts. The variance of wages is proportional to the square of the efficiency units price, but the variance of log wages is equal to the variance of log efficiency units. Figure 2 shows the variance of log wages for the relevant United States birth cohorts. While there is some noise, there is no evidence of any change in the variance that would violate the standard unit assumption for the United States data.

Table 1 presents the estimates for the United States obtained from all three approaches: the standard unit method using dropouts aged 18-20 in the earnings year, and the flat spot method applied to both dropouts and the university group (BA degree or higher). The flat spot method was implemented for both dropouts and those with a BA degree or higher using pairs of adjacent years and pooling the estimates of each pair assumed to be in a ten year flat spot region. An important result is that the flat spot series for a representative dropout group, using ages 48-57, and the university series, using ages 53-62, are very close to one another. The correlation between the series is .9455. The main requirement for the flat spot analysis is that the flat spot is correctly identified. General human capital theory suggests a flat spot towards the end of the working life-cycle. Figure 3 shows that for the United States the flat spot method is relatively insensitive to the age range chosen for the flat spot when the method is used on the dropout group. This might be expected as a reflection of relatively flat life-cycle human capital profiles for less educated groups. Figure 4 shows the sensitivity of the flat spot method applied to the university group. While there is more sensitivity for the university group, the overall patterns are the same.

Table 1 shows that the flatspot and standard units approaches produce closely related series. These series from Table 1 are plotted for comparison in Figure 5. The only significant difference is in the recovery after the 1981 recession where the standard unit approach indicates a larger drop relative to the other series. This provides substantial evidence that the use of a single price for human capital is a very good approximation. The credible regions for the flat spots show surprisingly similar price series for the two extremes on the human capital spectrum - the dropouts and those with a BA degree or higher. Since the dropouts leave school about 5 years earlier than those with a BA degree or higher, the flat spot region is likely to occur at an earlier age. The high correlation between the series based on the 48-57 region for dropouts and the 53-62 age region for those with a BA degree or higher is consistent with this. In addition, the price series using the standard unit approach is also similar. Despite the different paths of average wages for dropouts and those with a BA degree or higher, this evidence indicates that, rather than being due to different price paths for the two groups, it was due to different average efficiency units paths.

The last column of Table 1 shows a final price series to be used in computing the quantity series in Section 5. This is an average of the three series in Figure 5. For the overall change from 1975 to 2001, the average price series shows an 18% drop. The range of estimated overall declines in Table 1 is 15% to 20%. This range in part reflects the uncertainty of the flat spot range. For both the dropout and university groups, the earlier age group shows a smaller drop relative to the later age group. This is expected from the typical theoretical profile for human capital, where the later age group is either at a flatter part of the profile as it approaches the flat spot, inducing less of an upward bias in the estimated price than the younger group, or is beyond the flat spot, inducing a downward bias.

The price series for the United States shows a very strong decline to 1993 followed by a recovery. The percentage drop from 1975 to 1993 is about 24% and the recovery reduces the overall drop over the 1975-2001 period to 18%. There is a particularly steep decline in the first decade of almost 17%. This substantial decline to 1993 indicates a large increase in the supply of efficiency units relative to demand over the period. Only by the mid 1990's does the upswing in demand reverse the downward trend in the efficiency units price. It should be noted that this price series is quite different from what would be obtained from a conventional composition adjusted aggregate wage series. In particular, the price decline is much steeper than suggested by aggregate wage series. Thus, estimates of behavioural responses to the labour input price based on aggregate wage series are likely to be seriously biased.

The estimates for Canada are presented in Table 2. The standard unit group is similar to that used for the United States.[10] The Canadian data set is every five years instead of being annual. A flat spot method, corresponding as closely as possible to the method used for the United States, can be applied to the Canadian data set for the 1980-2000 period by following the same five year cohort group across adjacent five year censuses, such that in both censuses the age range of the cohort group remains within the ten year flat spot. The five year intervals may, however, increase the measurement errors due to the synthetic nature of the cohorts.

The first two columns of Table 2 report standard unit estimates for Canada. As discussed above, these are downward biased because of the decline in the cohort fractions in this group over time, and subject to the leap-frogging problems that selectively remove dropouts into the post-secondary group in a way that is difficult to detect with any precision. Inspection of the Canadian series in Figure 1 suggests that the bias may be significant in the earlier part of the series, as this shows the most rapid fall. The remaining columns of Table 2 report flat spot estimates for both dropouts and those with a BA degree or higher for a variety of possible flat-

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[10] A slightly older age group was chosen to minimize the problems of "leap-frogging" from the dropout to the post-secondary category over time in the Canadian data and results are presented for two alternatives. The problem arises from the changes over time in who leap-frogs out of the Canadian dropout group into post-secondary education - potentially a highly selective process. Many of these post-secondary certificates acquired by individuals without high school graduation are obtained by age 22. Starting the standard unit from this age removes these individuals from the dropout group, minimizing selective changes that would occur from changes in leap-frogging over time.

spot regions. The series are relatively insensitive to the choice of flat-spot region. Like the series for the United States, there is also strong similarity for the series of the two extremes of human capital levels. The correlation between the flat-spot series for the dropouts with flat spot region age 49-58, and any of the BA degree or higher series is always well above 0.9. Thus the evidence from Canadian data reinforces the evidence in Table 1 that a single price for human capital is a very good approximation. Comparison with the standard unit series shows, as expected, a downward bias in the standard unit estimates, especially in the earlier part of the series.

The last column in Table 2 reports the series average that is used to compute efficiency units in Section 5. Since the standard unit series for Canada suffer from potential bias problems, they were omitted in the averaging. Instead, the series in the last column is the average of the flat-spot series. Figure 6 compares the price series for Canada and the United States, normalizing both series to 1 in 1990. Until the recovery from the recession in the early 1990's, both series show a similar downward trend. Thereafter, the United States series shows a clear recovery in the price, while the price in Canada continues to decline. In 2000, there is a gap of 13 percentage points between Canada and the United States due to the continuing fall in the price in Canada and the increase in the United States after 1993. The average Canadian worker suffered a large loss in standard of living relative to the average United States worker. The price series in Figure 6 suggest that much of this was due to the relative decline in the price of human capital in Canada.

5. Stocks of Human Capital in Canada and the United States

In this section, the efficiency units price series estimated in Section 4, are used to derive the total supply of efficiency units in each country, and the per paid employee levels of efficiency units by sex. Total efficiency units in any period t, are, by definition:

$$N_t = \sum_j E_{jt} h_{jt}$$

where E_{jt} are the efficiency units supplied per hour by worker j in period t and h_{jt} are the hours for which those efficiency units are supplied. All firms pay the same price, λ_t, for hourly efficiency units in period t, so the hourly wage paid to worker j is:

$$w_{jt} = \lambda_t E_{jt}$$

and total period wage earnings for worker j are:

$$w_{jt} h_{jt} = \lambda_t E_{jt} h_{jt}$$

hence

$$N_t = \textstyle\sum_j (w_{jt} h_{jt})/\lambda_t \qquad (4)$$

Thus to compute a total efficiency units series the total wage payments are simply divided by the price series. For efficiency units for any sub-group, the relevant series can be computed using the wage payments to the sub-group.[11]

Comparison of efficiency units across countries raises many difficult issues.[12] However, the growth of efficiency units may be compared. In Table 3, the growth rates for 1980-2000 in wage and salary earnings and efficiency units per paid employee for Canada and the United States are shown. For all paid employees, the growth rate in earnings from 1980 to 2000 was 29.07% in the United States compared to 8.91% for Canada. Most of this growth occurs over 1990-2000. Relative to the position in 1980, Canadian paid workers thus experience a decline in standard of living compared to paid workers in the United States of 20%. A large part of this decline is due to the difference across countries in the price path of efficiency units shown in Figure 6. This is apparent in the columns reporting rates of growth of efficiency units for the two countries. For the United States the growth is 45.54% compared to 38.22% for Canada. Over

[11]This abstracts from discrimination. See the Appendix for adjustments required when there is discrimination.

[12]See Bowlus and Robinson (2005) for a discussion of the identification problems.

1990-2000, the growth in efficiency units is, in fact, marginally higher in Canada. Thus, while the relative standard of living decline is 20%, about two thirds of this is due to the different price path (13%), and only one third to the different rates of growth in the amounts of human capital supplied (7%).

For males, the growth rate in earnings from 1980 to 2000 is 21.88% in the United States compared to 3.68% in Canada. The 1990-2000 period represents almost all of the growth in earnings in both countries. Again, there is a large decline in standard of living for Canadian male workers relative to those in the United States, of about 18%, with at least two thirds (13%) due to the lower price for human capital in Canada in 2000. The per worker efficiency units for males did grow faster in the United States (37.42%) compared to Canada (31.58%), but this accounts for only one third of the decline in the relative standard of living. From 1990 to 2000, where the price decline in Canada was 13% compared to zero in the United States, per worker human capital actually grew marginally faster for males in Canada compared to males in the United States. The pattern for females is similar. The primary difference is that the rates of growth in efficiency units for females are about 25 percentage points higher in both countries. Overall, the growth for females was somewhat higher in the United States (70.35%) compared to Canada (63.35%), but in the most recent decade the rate of growth in Canada surpassed that of the United States.

The total supplies of paid workers and efficiency units in the economies of Canada and the United States are presented in Table 4. The rates of growth in the total paid worker population for 1980-2000 are very similar in the two countries: 29.44% in the United States, compared to 28.72% in Canada. The United States, however, has a larger growth in efficiency units: 88.38% vs. 77.92%. In the most recent decade, the population of paid workers in the United States grew considerably more than in Canada (13.91% vs. 9.22%), but efficiency units grew at a similar rate in the two countries (35.78% vs. 34.25%). The breakdown by sex shows that the faster growth in paid workers in the United States was due to the differential growth for males. Both the number of male paid workers and total efficiency units increase at a faster rate in the United States. Growth in the number of paid workers is 23.39% in the United States compared to 18.20% in Canada. This is reflected in the faster growth in efficiency units for males: 69.57% in the United States compared to 55.53% in Canada. For females , the population growth from 1980 to 2000 was higher in Canada (42.19% vs. 36.47%), but this was not reflected in a higher growth in efficiency units. Efficiency units grew at the same rate in both countries. Most of the paid worker population growth for females in Canada occurred in the 1980s, largely due to a faster increase in the employment rate for females in Canada.

As discussed in the Appendix, the computation of efficiency units for females depends on the magnitude of wage discrimination against females and its path over time. In addition, the change in per worker efficiency units are affected by the rise in female participation over time. In Tables 3 & 4 the efficiency units are all calculated under the assumption of no discrimination. The comparison across countries for males is not complicated by these issues, and is less affected by different labour supply paths in the two countries over time. The sensitivity of the estimates of rates of growth of the total labour input to alternative assumptions regarding discrimination is considered further in the following section.

6. Comparison of Human Capital Quantity Series with Standard Composition Adjusted Aggregate Hours Series

The quantity series presented in Section 5 are substantially different from conventional series based on composition adjusted aggregate hours. Since the composition adjusted series account for changes in the proportions of workers with different education levels in the labour market, the differences between conventional series and those presented in Section 5 reflect the effect of technological change in the production function for human capital. In general, the series estimated in Section 5 show significant amounts of technological improvement. In this section, the human capital quantity series, allowing for technological change, are compared with the most well known composition adjusted series for the United States, and with similarly constructed series for Canada.

Aggregate Labour Input Measures for the United States

The BLS provides the main official composition adjusted series for the United States as part of its Multi-factor Productivity Program. The motivation for the series is described in BLS *Bulletin 2426* (1993).[13] Prior to this series, labour input had been measured by the total hours of all workers. It was widely recognized that "the effective quantity of labor input does not rest solely on the total number of hours worked by members of the U.S. labor force but also on characteristics of the labor force." (p. iii). Following the recommendations of a National Academy of Sciences Panel to Review Productivity Statistics in 1979 the BLS developed a weighted measure of total hours focusing on the skill level of workers as reflected in education and job market experience levels. This measure is used in the construction of the BLS multi-factor productivity index. It results in a substantially different interpretation of the path of multi-factor productivity in the United States than estimates obtained using an unweighted aggregate hours measure.

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. The hours measures used in the original BLS *Bulletin 2426* (1993) study for the period 1968-1990 were obtained from the MCPS. For the current series for the BLS Multi-factor Productivity Program, hours are obtained mainly from the BLS Current Employment Statistics (CES) program, based on establishment surveys. They are supplemented by data from the CPS and other sources for groups not covered under CES. The weights are the shares of total compensation for each type of worker classified by skill and demographic characteristics. They are allowed to vary each year.

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

Prior to the development of the BLS measure, a number of authors had developed and published composition adjusted aggregate hours series.[14] The most well known current version of these is the Jorgenson series for the United States private economy, 1977-2000.[15] There are some differences in the details of the methods and coverage, but the basic methodological approach is the same for both the Jorgenson and BLS series, and the two series are very similar for the 1977-2000 period. The series are given in Table 5. The first two columns show the aggregate hours for the private economy. The coverage is a little broader for Jorgenson's series, but the pattern is the same. Overall growth in aggregate hours from 1977 to 2000 for the Jorgenson series is 53.39% compared to 50.42% in the BLS series. The next two columns report the composition adjustment factor with 2000 as the base.[16] The adjustment factors for the Jorgenson and BLS series are almost the same. The final three columns report the composition adjusted labor input. In the first of these, the Jorgenson series is higher than the BLS series, despite the similar composition adjustment factors, because of the wider coverage. The last two columns show that, when the Jorgenson series is scaled to the BLS series in 1977, the two labour input series look almost the same.

The growth in the labour input series that adjusts for composition is substantially higher than the aggregate hours growth. Using the BLS figures in Table 5, the hours growth is 50.42%, but the composition adjusted input growth is 66.68%. Thus, the changing composition contributed almost one quarter of the total growth in the composition adjusted input. Since the growth rate using composition adjusted hours is almost one third higher than when using hours, the use of hours in constructing the MFP would substantially bias the change in the index over this period. Adjusting hours for composition changes is clearly important. However, because it ignores technological change in human capital production, and endogenous choice of human

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[14]See, for example, Chinloy (1980), Denison (1985) and Jorgenson, Gollop and Fraumeni (1987).

[15]Available at: http://post.economics.harvard.edu/faculty/jorgenson/papers/lqualprivate.xls

[16]The published Jorgenson series has 1996 as the base and was adjusted to 2000 to match the base year for the published BLS series.

capital investment, the composition adjusted series itself is subject to bias. In the presence of technological improvement, composition adjustments to aggregate hours, like those of the BLS or Jorgenson's, will still underestimate the true labour input.

To estimate the magnitude of the bias for the United States, we use a single data set, the MCPS, to construct three measures of the labour input: an aggregate hours measure, a BLS/Jorgenson style composition adjusted aggregate hours measure, and the efficiency units measure reported in Section 5. Comparisons between these three measures have a simple interpretation within the efficiency units framework. The BLS measure uses a Tornqvist chained index. Divide hours of labour into N skill groups where all members are the same "quality", i.e. the same efficiency units per hour. For the BLS these are groups based primarily on sex, education and experience. Define the price of labour (average hourly wage rate) in group i at year t, ν_{it}, implicitly as:

$$\nu_{it} = W_{it}/h_{it}$$

where W_{it} is total labour compensation in group i, in year t, and h_{it} is the total number of hours. Let E_{it} be efficiency units per hour for a member of group i. The construction of the Tornqvist chain index of composition adjusted labour input used by the BLS is as follows. For group i the ratio of the labour input in year t to the input in $t\text{-}1$ is by definition:

$$L_{i,t/t-1} = E_{it}h_{it}/E_{it-1}h_{it-1}$$

In the BLS approach, there is an implicit assumption that there is no change in efficiency units per hour within the group (E_{it}=E_{it-1}), so that

$$L_{i,t/t-1} = E_{it}h_{it}/E_{it-1}h_{it-1} = h_{it}/h_{it-1}$$

Aggregating across groups, the Tornqvist chained index (ratio) of the total labour input in year t

to the input in $t\text{-}1$ is given by weighting the ratios of the groups as follows:

$$L_{t/t-1} = (L_t/L_{t-1}) = \prod (h_{it}/h_{it-1})^{w(it)} \qquad \text{or} \qquad ln\,(L_t/L_{t-1}) = \sum w_{it}\, ln(h_{it}/h_{it-1})$$

where

$$w_{it} = (W_{it}/(\sum W_{it}) + W_{it-1}/(\sum W_{it-1}))/2 \; = (\nu_{it}h_{it}/\sum \nu_{it}h_{it} + \nu_{it-1}h_{it-1}/\sum \nu_{it-1}h_{it-1})/2$$

If $E_{it} = E_{it-1}$, this weighted sum of the approximate percentage growth in the hours of each group is also a weighted sum of the approximate percentage growth in the efficiency units of each group, where the total efficiency units of group i in period t are $N_{it} = E_{it}h_{it}$.

The BLS series from an initial period zero to t follows by chaining the ratios, $L_{t/t-1}$, to get the change from zero to t:

$$\Delta L_{t/0} = L_{t/t-1}L_{t-1/t-2}\ldots L_{1/0}$$

so that the value in any period t is given by:

$$L_t = L_{t/t-1}L_{t-1/t-2}\ldots L_{1/0}L_0$$

where L_0 is some normalized value in period zero. If $E_{it} = E_{it-1}$, this is equivalent to a total efficiency units series.

In our efficiency unit measure, the assumption that there is no change over time in efficiency units within any group is dropped. Aggregation in our efficiency units framework is simple:

$$N_t = \sum N_{it} = \sum E_{it}h_{it} \qquad \text{and} \qquad N_{t-1} = \sum N_{it-1} = \sum E_{it-1}h_{it-1}$$

so that:

$$L_{t/t-1} = (\sum E_{it}h_{it})/\sum E_{it-1}h_{it-1}$$

However, comparison with the composition adjustment approach is easier if a parallel approach is taken to deal with composition in both cases.

In the BLS approach, the natural logs of the labour input (total efficiency units) ratios for each group are weighted by the share in total efficiency units:

$$lnL_{t/t-1} = \sum w_{it}\, ln(E_{it}h_{it}/E_{it-1}h_{it-1}) = \sum w_{it}\, ln(h_{it}/h_{it-1}), \qquad E_{it}=E_{it-1}$$

By assumption $E_{it}=E_{it-1}$, so it is equivalent to a weighting of the percentage growth in hours of the groups to get the percentage growth in the composition adjusted total. The equivalent approach to composition weighting in our efficiency units measure is:

$$lnL_{t/t-1} = \sum w_{it}\, ln(E_{it}h_{it}/E_{it-1}h_{it-1}) = \sum w_{it} ln(E_{it}/E_{it-1})(h_{it}/h_{it-1})$$

$$= \sum w_{it} ln(h_{it}/h_{it-1}) + \sum w_{it} ln(E_{it}/E_{it-1}) \qquad (5)$$

The first term in equation (5) is the same as the composition adjusted hours index. However, there is also a second term which is the weighted sum of the percentage changes in average efficiency units per hour, or quality, *within* group. This term is non-zero whenever any group has a change in average efficiency units per hour over time, i.e. an average quality change via technological change or selection effects.

Table 6 compares the alternative labour input series estimated using the MCPS. The BLS-style (Tornqvist) composition adjusted series was calculated as described above, using 120 groups classified by education, age and sex for a population of private paid workers aged 20-64. An additional composition adjusted series was computed using the Fisher chained index (used in Canada) instead of the Tornqvist index. The first column reports the aggregate hours estimate from the MCPS.[17] The growth in hours is substantially less than the growth in the composition

[17]The March supplement weights were used for all the total estimates.

adjusted hours which are reported in the third and fourth columns. The growth in composition adjusted hours is itself substantially less than the growth in efficiency units reported in the final column of Table 6. The same series for the population of all paid workers, 20-64, are reported in Table 7 and show the same pattern. 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 technological change.

The magnitudes of the differences are very large: efficiency units grow almost twice as fast as hours. The magnitudes of the differences in the growth rates are shown in Table 8. Unadjusted hours of private sector paid workers for the period 1977 to 2000 has a growth rate of 67.72% ; composition adjusted hours grow by just over 90%. The composition adjustment thus produces a labour input growth that is about one third higher than the unadjusted hours growth. However, the growth in efficiency units is 124.42% , which is a labour input growth rate that is almost 40% higher than the growth rate of composition adjusted hours. The composition adjustment is therefore less than half of the full adjustment to aggregate hours that is necessary to estimate labour input growth between 1977 and 2000. The pattern is similar for the full 1975-2001 period for which efficiency units have been estimated, and for the sample of all paid workers.

Table 8 also reports the growth rates of alternative labour input measures by sex. The BLS method for total hours uses compensation shares to weight the growth of each "type" of hours, including male vs. female. The logic of this weighting suggests that to get separate totals for males and females, the total labour 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). By construction, the relative rates of growth in the BLS (B) measures of the labour input by sex simply reflect the relative rates of growth of hours.

Human capital theory predicts that the increased labour market attachment of females 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 college. This increase has resulted in an increase in the total labour input of females by all measures, including total hours. Total hours for female private workers increased by 100.10% from 1977 to 2000, which is double the growth in male hours of 49.50%. The same pattern occurs for all paid workers: female hours increase by 90.98% and male hours by 42.75%. The growth in efficiency units (EUS) for females, however, is particularly pronounced. From 1977 to 2000 the growth in efficiency units for females is 211.22%, which is more than double the growth in hours. By contrast, much smaller rates of growth are estimated using the BLS style measures: 163.93% for BLS (A) and 137.68% for BLS (B).

The BLS (A) measure for females in Table 8 is closer to the efficiency units increase because the use of the compensation shares to apportion the total in the BLS (A) case captures the relative increase for females over time in efficiency units per hour within observed skill cells. The female growth rates relative to males using BLS (B) by construction reflect the relative rates of growth of hours. The female growth rates are depressed relative to males. This is a reflection of the fact that the compensation weighted method cannot adequately capture changes in the efficiency units per hour of any group. In particular, it is unable to capture the effects of higher human capital investments of females accompanying the rise in their labour force participation, including the move to more market oriented human capital investments in their college education. The same problem occurs more generally, as shown in equation (5) above, for capturing any overall increase in efficiency units per hour for any group.

The use of compensation shares in the BLS method implicitly assumes that the wage rate for females reflects the true marginal product, i.e. that there is no discrimination. The estimates of total efficiency units in Tables 6 & 7 are also based on this assumption. If discrimination creates a significant difference between the wage and the marginal product of female labour, 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 the true efficiency series is 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.[18] If, for example, discrimination against females was 10% in 1975, declining to zero in 2001, the growth in total efficiency units from 1975 to 2001 for paid workers would have been 131.25% instead of the 137.40% reported in Table 8.

Aggregate Labour Input Measures for Canada

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, as shown in Tables 6 & 7, 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 is being developed.[19] The most recent estimates from this approach are presented in Gu *et.al.* (2002).

In this section, the alternative estimates of the labour input for Canada are presented.

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[18]See the Appendix for more details.

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

Table 9 reports the estimates for all paid workers for 1980-2000, using the censuses of 1981-2001. The alternative estimators are the same as for the United States. Columns 1 & 2 report the unadjusted hours; columns 3 & 4 report composition adjusted hours; and column 5 presents the efficiency units estimates, using the price series from Section 5. The growth rates are reported in Table 10, with comparable growth rates for the same period from the United States. The patterns for Canada are remarkably similar to those for the United States. Table 10 shows that total unadjusted hours grow faster in the United States, due to the faster growth in hours for males in the United States. The top half of Table 10 shows that for the United States the growth in total hours is 46.99% in the United States compared to 40.49% in Canada. The growth in female hours is slightly higher in Canada (67.09% vs. 63.77%) but male hours grow much slower in Canada (25.14% vs. 35.73%).

The BLS style composition adjustment to total hours is almost identical in both countries. In Canada it adjusts total hours upwards by 16.3 percentage points compared to 17.3 in the United States. The composition adjustments results in estimated rates of growth in the labour input in both countries that are 36-40% higher compared to unadjusted hours. However, as for the United States, the composition adjustment in Canada falls a long way short of the growth in efficiency units. In both countries, the rate of growth of efficiency units is about 40% faster than the rate of growth of composition adjusted hours.

In the United States the growth rate of efficiency units is 90.11%, which is ten percentage points higher than Canada's rate of 79.43%. Roughly two thirds is due to faster growth of hours in the United States and one third to a faster growth in efficiency units per hour. However, BLS style comparisons cannot identify the main source of the difference in efficiency units per hour across countries because only a very small part of the cross country difference in the growth in efficiency units per hour is due to composition differences.

Aggregate Series in the Business Cycle and Macroeconomics Literature

In addition to the Jorgenson series and official aggregate labour input measures, other measures of aggregate input, focusing on composition adjustment, have been constructed in a variety of studies in the business cycle literature, and the macroeconomics literature generally. Studies of wage cyclicality, recently reviewed in Bowlus, Liu and Robinson (2002), are concerned with the effects of a downward "composition bias" on the estimates of the correlation between wages and the labour input over the cycle. In tackling the problem of composition bias, these studies implicitly or explicitly construct aggregate wage and hours measures that are designed to address quality variation in the human capital input over the cycle induced by composition changes. Examples of these series include Hansen (1993) and Kydland and Prescott (1993) for a total economy 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 fixed weights for the entire period, which implicitly assumes no technological change or selection, and therefore suffer from the same type of bias as the BLS and Jorgenson estimates, to which they are related.[20]

To examine the magnitude of the under-estimate of the labour input using the fixed weight efficiency units methods we constructed efficiency unit aggregates by skill and in total using a method analogous to Krusell *et. al.* (2000) and Kydland and Prescott (1989). 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 demographic and other variables such as age, sex and education. While the BLS and Jorgenson methods use chained indexes of weighted hours growth rates with varying weights, the fixed weight methods simply compute the hourly efficiency units of a worker of any given type as the average hourly wage of workers of that type. Applying the fixed weight efficiency unit method to all workers yields a total labor input in period t of:

$$I_t = \sum_j (W_j H_{jt}), \qquad j = 1,2,\ldots J$$

[20]Krusell *et. al.* (2000) use the weights from the year 1980 for the whole period 1964-1993; Kydland and Prescott (1993) use the weights from averaging across all years.

where H_{jt} is total hours of workers of type j in year t, W_j is the average wage of workers of type j in the reference year (or averaged over all years), and J is the number of worker types. Similarly, total labour inputs for particular skills defined by subsets of the J worker types, such as unskilled (U) and skilled (S) are given by:

$$U_t = \sum_{j\in U} (W_j H_{jt})$$

and

$$S_t = \sum_{j\in S} (W_j H_{jt})$$

The estimates from the fixed weight methods for the United States are presented in Table 11. The top half of Table 11 reports the estimates for an aggregate labour input across skills. The rates of growth of hours, efficiency units and the BLS style measure are repeated from Table 8. The results show that the composition adjustment applied to aggregate hours implied by the fixed weight approach is almost identical to the BLS style methods and therefore has the same degree of underestimate of the increase in the labour input.

The lower half of Table 11 reports separate estimates for skilled and unskilled workers, defined analogously to Krusell *et. al.* (2000), using weights averaged across years as in Kydland and Prescott (1989). The results show that within both skill types defined by observed education level, the fixed weight estimates produce growth rates that are lower than the EUS estimate. The under-estimate is higher for the skilled group, but even for the unskilled efficiency units grow almost 30% more than indicated by the fixed weight estimates. Indeed, the fixed weight estimates differ relatively little from the hours changes, especially for the skilled group. Overall, the results from Table 11 provide further indication that composition adjustment methods may substantially under-estimate the rate of growth of the labour input. Fixed weight methods, by construction, do not permit total efficiency units of labour 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 comparison, it is potentially extremely important. One important consequence is the potential for serious overestimation of multi-factor productivity and under-estimation of the role of human capital in growth.

7. Consequences for Multi-factor Productivity

A major motivation for the construction of "quality" adjusted labour 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 or TFP.[21] Since changes in MFP and TFP are defined as the residual change in output that cannot be accounted for by the changes in the inputs, the estimates of these changes depend on the estimates of the changes in the inputs. Define l as the growth in the true labour input, h as the growth in aggregate hours, and h^c as the growth in composition adjusted hours. Then the over-estimate of the growth in MFP from using h in place of l is:

$$s_l\,[l - h]$$

and the over-estimate of the growth in MFP from using h^c in place of l is:

$$s_l\,[l - h^c]$$

where s_l is the share of labour in total costs.

The results in Section 6 indicate that adjusting for composition falls a long way short of a full quality adjustment, since it cannot capture technological change in human capital production or increased human capital investment by females. For the United States for the period 1975 to 2001, the growth in hours under-estimates the growth in efficiency units by 70.94 percentage points. Since the share of labour in total costs is roughly two thirds,[22] this implies an over-estimate of the growth of MFP of almost 50 percentage points. Using composition adjusted hours under-estimates the growth in efficiency units by 45.46 percentage points, hence this adjustment still implies an over-estimate of the growth of MFP of over 30 percentage points. The BLS

[21] In the official series for the United States and Canada, MFP is defined in the same way.

[22] The BLS estimates for labour share in total cost are 0.678 in 1975 and 0.686 in 2001.

estimate of MFP growth in the private business sector between 1975 and 2001 is 23.76%.[23] The results therefore suggest that all of this is due to an undercount of the increase in the labour input.

For Canada, for the 1980 to 2000 period, efficiency units for paid workers grew by 38.94 percentage points more than unadjusted hours and 22.64 percentage points more than composition adjusted hours. The labour 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 15 percentage points over the 1980 to 2000 period. This is as large as conventional estimates of MFP growth for the period, suggesting again that all the estimated growth is actually due to an undercount of the increase in the labour 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. 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. In particular, composition adjustment cannot capture a change in the level of human capital accumulated by college educated workers from the 1966 birth cohort compared to the level accumulated by an otherwise identical individual from the 1946 birth cohort.

The results for both countries show an extremely large effect on the estimates of MFP when quality variation across time in the labour 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.[24] In a recent paper that re-opens the

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[23]See Table PB4a in mfp2ddod.txt at the BLS Multi-factor Productivity website.

[24]See footnote #3 above.

question on the sources of cross country variation in wealth, Manuelli and Seshadri (2005) argue that quality differences in human capital, that are not captured by observed measures that are typically used in composition adjustments, substantially reduce the role of MFP or TFP differences in explaining cross country differences in wealth. Their estimates show very little cross country difference in TFP 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. These results mirror the findings in this section that there is little difference across time within countries in MFP when the quality of human capital is taken into account.

9. Conclusions

Human capital is widely recognized as the most important asset that individuals hold. Unfortunately, it is not directly observed. As a result previous research has relied on a variety of proxies based on observable characteristics such as years of schooling. For a variety of purposes, such as within country variation in wages for a given cohort, these proxies can work quite well and have formed the basis of thousands of studies. For issues of secular growth, cross country variation and cross cohort variation in wages, however, they may leave out the most important source of progress or variation due to technological change in human capital production, broadly interpreted. In order to estimate this change in the quality of human capital corresponding to a given observed proxy such as years of schooling, it is necessary to separately identify the price and the quantity of human capital from the readily available wage observations.

In this paper estimates of human capital prices and quantities are presented for both Canada and the United States for the same period, and the implications of the estimates for the sources of growth are examined. The estimated quantity series have important implications for the source of standard of living improvements in the two countries. The most striking result is that adjusting the labour input for quality changes by using the estimated quantity series reduces the contribution of MFP growth in standard of living growth to zero. This parallels the recent result in Manuelli and Seshadri (2005) that quality adjustment to international comparisons of human capital comes close to eliminating MFP differences as the source of cross country differences in wealth. The largest part of this quality increase is not due to composition changes but instead to technological change in human capital production. Since most attempts at adjusting the labour input for quality changes, such as Krusell *et. al.* (2000) or the official BLS series used to estimate MFP, only deal with composition, they cannot capture a large part of the quality change. While our paper does not provide direct estimates of technological improvement in human capital production, large differences are found between estimated efficiency units and composition adjusted hours measures suggesting that technological improvement in human capital production could be the major source of standard of living growth in the last few decades.

An important result for the analysis of cross country differences in standard of living is that both prices and quantities of human capital can play significant roles. Much of the difference in standard of living that opened up between Canada and the United States, particularly in the 1990's is found to be due to the different paths that the price of human capital took in the two countries. In particular, while the price of human capital fell in both countries throughout the 1980's and early 1990's, the price in the United States subsequently began a substantial recovery, in contrast to the continued decline in Canada. Since the wage a worker receives is the product of the (rental) price of human capital and the amount of human capital he or she has for rent, the change in the wage can be decomposed into price and quantity changes. The average Canadian worker fell behind the average United States worker mainly due to the fall in the relative price received for the human capital rented, rather than from any deficiency in the quantity of human capital. It is an interesting topic for future work to examine the relative importance of price and quantity differences in explaining more general cross country variation in labour income.

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TABLE 1

Efficiency Units Price Series for United States, 1975-2001

	Standard Unit	Flat Spot (Dropouts)		Flat spot (University)		Average Series
Year		Age 46-55	Age 48-57	Age 50-59	Age 53-62	
1975	1	1	1	1	1	1
1976	0.9924259	1.02371	1.025424	1.007199	0.995433	1.004095
1977	0.9802408	1.010936	1.004362	1.008081	0.9941186	0.993065
1978	1.020582	1.011398	1.010743	0.9797081	0.9876342	1.005885
1979	0.9609066	0.9640547	0.9745797	0.9462874	0.9750662	0.9697691
1980	0.9179272	0.9314943	0.9346712	0.9158245	0.9090757	0.9204969
1981	0.9015074	0.9215152	0.9336614	0.9154244	0.9039088	0.912473
1982	0.8314961	0.8711348	0.8635144	0.9132852	0.9078457	0.8676744
1983	0.8006828	0.8967901	0.8981088	0.9262186	0.8660981	0.8546029
1984	0.781473	0.8926303	0.8855972	0.9065009	0.8162192	0.8280677
1985	0.7954459	0.8886022	0.8802447	0.8975758	0.84365	0.8398126
1986	0.7550431	0.8852324	0.8726529	0.9237816	0.8770908	0.8353737
1987	0.79483	0.8931988	0.8841341	0.8741345	0.8141932	0.8295785
1988	0.7842304	0.8460958	0.8497909	0.8799793	0.81705	0.8163155
1989	0.8394979	0.8116889	0.8212289	0.8798855	0.8476898	0.8357374
1990	0.7884215	0.7870647	0.811418	0.8318653	0.8284196	0.8107247
1991	0.7496412	0.7698971	0.8016593	0.8182037	0.8158712	0.7874804
1992	0.7470589	0.7829636	0.7958211	0.8092295	0.7998775	0.7812459
1993	0.7359942	0.7524555	0.7682582	0.7951002	0.7826514	0.7609652
1994	0.7478261	0.8121357	0.8264995	0.8159364	0.8063873	0.7922372
1995	0.8047488	0.7736447	0.800245	0.8135469	0.7460631	0.7815578
1996	0.8069699	0.805069	0.7968113	0.7927842	0.7806987	0.7968555

1997	0.7703621	0.7689855	0.7602649	0.8113918	0.7977348	0.7756618
1998	0.8196947	0.8000832	0.7855259	0.839236	0.8318172	0.8112343
1999	0.8366837	0.8069197	0.8143474	0.8837759	0.8552672	0.8379319
2000	0.8167102	0.7996168	0.7967138	0.854462	0.8365989	0.8163815
2001	0.838245	0.8228635	0.7992771	0.848218	0.8226217	0.8192139

TABLE 2

Efficiency Units Price Series for Canada, 1980-2000

	Standard Unit		Flat Spot (Dropouts)			Flat spot (University)			Average Series
Year	Age 19-23	Age 21-25	Age 48-57	Age 49-58	Age 51-60	Age 50-59	Age 51-60	Age 53-62	
1980	1	1	1	1	1	1	1	1	1
1985	0.8371	0.8569	0.9491	0.9454	0.9462	0.9647	0.9363	0.9428	0.9474
1990	0.8085	0.8309	0.9265	0.9103	0.9046	0.8883	0.8828	0.9071	0.9031
1995	0.7316	0.7444	0.8782	0.8437	0.808	0.8528	0.8541	0.8476	0.8474
2000	0.7482	0.7464	0.8545	0.8061	0.7604	0.7989	0.7951	0.7686	0.7879

Notes: The sample consists of male paid employees, working mainly full-time last year for 48-52 weeks.

Table 3

Rates of Growth in Per Worker Earnings and Efficiency Units:

Paid Workers, 16-64; Canada and the United States, 1980-2000

	United States				Canada			
	1980-2000		1990-2000		1980-2000		1990-2000	
	W&S	EUS	W&S	EUS	W&S	EUS	W&S	EUS
PAID EMPLOYEES	0.2907	0.4554	0.2003	0.192	0.089	0.3822	0.072	0.2291
Males	0.2188	0.3742	0.1971	0.1888	0.037	0.3158	0.048	0.2013
Females	0.5108	0.7035	0.2166	0.2081	0.287	0.6335	0.1318	0.2973

Notes: W&S are wages and salaries; EUS are efficiency units

Table 4

Rates of Growth in Paid Workers and Total Efficiency Units:

Paid Workers, 16-64; Canada and the United States, 1980-2000

	United States				Canada			
	1980-2000		1990-2000		1980-2000		1990-2000	
	POP	EUS	POP	EUS	POP	EUS	POP	EUS
PAID EMPLOYEES	0.2944	0.8838	0.1391	0.3578	0.2872	0.7792	0.092	0.3425
Males	0.2339	0.6957	0.1245	0.3369	0.182	0.5553	0.068	0.2828
Females	0.3647	1.3247	0.1547	0.3951	0.4219	1.3227	0.1195	0.4523

Notes: POP is the population of paid workers, 16-64; EUS are efficiency units

TABLE 5

BLS and Jorgenson Composition Adjusted Labor Input Series, 1977-2000

	Total Hours (billions)		Composition Adjustment		Labor Input		
	Jorgenson	BLS	Jorgenson	BLS	Jorgenson	Jorgenson*	BLS
1977	145.3967	127.413	0.909	0.902	132.129	114.984	114.984
1978	152.4866	133.839	0.91	0.904	138.723	120.752	120.926
1979	157.8711	138.333	0.911	0.901	143.778	125.091	124.597
1980	156.109	137.054	0.909	0.904	141.864	123.453	123.831
1981	157.1794	138.051	0.917	0.91	144.082	125.322	125.645
1982	153.9752	134.803	0.923	0.919	142.061	123.611	123.948
1983	156.7416	137.183	0.924	0.923	144.768	126.022	126.669
1984	165.4984	145.238	0.933	0.924	154.332	134.238	134.262
1985	169.1046	148.597	0.935	0.927	158.03	137.457	137.7
1986	169.9429	149.594	0.936	0.931	158.982	138.357	139.293
1987	175.6338	154.034	0.941	0.934	165.35	143.807	143.802
1988	180.7782	158.274	0.945	0.941	170.91	148.689	148.93
1989	186.0455	162.533	0.949	0.945	176.628	153.695	153.618
1990	187.2754	161.648	0.958	0.95	179.465	156.175	153.567
1991	183.2378	157.851	0.961	0.961	176.141	153.295	151.664
1992	183.5965	157.69	0.967	0.973	177.577	154.492	153.365
1993	188.5939	162.105	0.976	0.975	184.093	160.263	158.021
1994	194.2605	168.309	0.981	0.98	190.587	165.891	164.937
1995	199.4712	172.948	0.983	0.981	196.095	170.647	169.634
1996	202.7156	175.828	0.991	0.985	200.891	174.805	173.211
1997	209.1744	181.831	0.992	0.991	207.499	180.54	180.116
1998	215.2336	185.709	0.995	0.993	214.15	186.268	184.463
1999	219.4094	189.814	0.997	1	218.739	190.387	189.721
2000	223.0287	191.66	1	1	223.011	194.016	191.66

TABLE 6

Comparison of Alternative Labor Input Series, Private Sector: 1977-2000

	Unadjusted Hours		Composition Adjusted Hours		
	Total (billions)	Index	Tornqvist	Fisher	Efficiency Units
1977	117.7537	108.0142	107.8179	107.8203	110.7096
1978	123.1152	112.9323	112.7404	112.738	114.6653
1979	125.6677	115.2737	114.6705	114.6627	119.8709
1980	129.668	118.9431	118.661	118.6538	125.9492
1981	131.0276	120.1902	120.711	120.7007	125.7318
1982	129.3289	118.6321	120.1273	120.1152	131.1217
1983	132.8805	121.89	123.5739	123.5593	137.0077
1984	140.7109	129.0726	131.5091	131.4955	149.1265
1985	146.9159	134.7644	138.4073	138.3927	156.2929
1986	150.8217	138.3472	142.724	142.704	165.0377
1987	154.1638	141.4129	146.1551	146.1363	169.6338
1988	157.853	144.797	150.7242	150.703	177.1621
1989	160.5897	147.3073	154.4506	154.4276	176.0129
1990	161.7545	148.3758	156.256	156.2293	177.4606
1991	162.2436	148.8244	158.1804	158.1655	181.5416
1992	162.7781	149.3147	160.9345	160.9159	185.1691
1993	165.7894	152.077	165.2209	165.1985	193.1801
1994	171.3907	157.2149	172.2097	172.1854	195.7264
1995	177.688	162.9913	178.8962	178.871	204.8792
1996	180.9425	165.9767	183.1756	183.1424	209.0209
1997	185.6065	170.255	188.9621	188.9233	225.6051
1998	190.6858	174.9142	196.1496	196.1101	228.9369
1999	193.1994	177.2199	200.1184	200.0786	229.5816
2000	197.5009	181.1655	205.178	205.1418	248.4539

Notes: See the Appendix for cell definitions.

TABLE 7

Comparison of Alternative Labor Input Series, Paid Workers: 1977-2000

	Unadjusted Hours		Composition Adjusted Hours		
	Total	Index	Tornqvist	Fisher	Efficiency Units
1977	146.2455	106.5429	106.5563	106.558	109.0206
1978	152.5765	111.1551	111.1707	111.1721	112.242
1979	155.6163	113.3697	113.3093	113.308	117.0975
1980	160.1237	116.6534	116.8424	116.842	122.5305
1981	161.009	117.2984	118.1511	118.1517	121.7774
1982	158.9353	115.7877	117.4353	117.4346	127.073
1983	163.7512	119.2961	121.3482	121.3429	133.5293
1984	172.2239	125.4687	128.1364	128.1326	144.7282
1985	178.1313	129.7723	133.1505	133.1462	150.2028
1986	182.9356	133.2724	137.3454	137.34	158.8784
1987	187.0298	136.2551	140.737	140.7325	163.2148
1988	191.5991	139.5839	145.2336	145.2285	170.614
1989	195.0625	142.1071	148.6597	148.654	170.0605
1990	195.785	142.6334	149.7317	149.7217	171.4322
1991	197.1212	143.6069	152.1546	152.1538	176.5182
1992	198.7658	144.805	155.289	155.2876	180.6833
1993	202.3861	147.4425	159.1748	159.1729	188.7787
1994	208.1018	151.6065	165.1147	165.1094	189.9753
1995	213.127	155.2675	169.105	169.098	196.3288
1996	215.9565	157.3288	171.8405	171.8323	197.7664
1997	221.2122	161.1577	177.0715	177.0609	212.9827
1998	227.0704	165.4255	183.4849	183.4713	215.2639
1999	231.0326	168.3121	187.553	187.5397	216.8229
2000	235.3721	171.4735	191.6503	191.6385	232.9429

Notes: See the Appendix for cell definitions

TABLE 8

Comparison of the Growth Rates of Alternative Labour Input Series for the United States

	%Δ1975-2001		%Δ1977-2000	
	Private Sector Paid Workers 20-64 (120 cells)			
EUS	153.69		124.42	
hours	82.75		67.72	
BLS	108.33		90.3	
	Males	Females	Males	Females
EUS	116.03	272.69	95.53	211.22
hours	61.34	122.06	49.5	100.1
BLS (A)	77.42	205.99	65.78	163.93
BLS (B)	88.66	167.4	73.81	137.68
	Paid Workers 20-64 (120 cells)			
EUS	137.4		113.67	
hours	72.83		60.94	
BLS	94.31		79.86	
	Males	Females	Males	Females
EUS	101.61	236.06	85.58	188.63
hours	51.63	108.91	42.75	90.98
BLS (A)	65.03	175.06	56.21	142.93
BLS (B)	74.7	145.88	63.24	122.01

TABLE 9

Comparison of Alternative Labor Input Series, Paid Workers: 1980-2000

	Unadjusted Hours		Composition Adjusted Hours		Efficiency Units
	Total (billions)	Index	Tornqvist	Fisher	
1980	16.5852	100	100	100	100
1985	17.7883	107.2542	109.5616	109.5616	108.7573
1990	20.1829	121.6924	128.0497	127.9724	133.2765
1995	20.3272	122.5624	134.3498	134.2734	139.8786
2000	23.3004	140.4892	156.7929	156.7423	179.4353

Notes: See the Appendix for cell definitions

TABLE 10

Comparison of the Growth Rates of Alternative Labour Input Series:

Paid Workers 20-24, Canada and the United States, 1980-2000

	Canada		United States	
EUS	79.43		90.11	
hours	40.49		46.99	
BLS	56.79		64.02	
	Males	Females	Males	Females
EUS	56.25	136.6	70.74	136.04
hours	25.14	67.09	35.73	63.77
BLS (A)	36.51	106.79	47.32	103.61
BLS (B)	40.29	95.74	53.71	86.77

TABLE 11

Growth Rates of Fixed Weight Labour Input Series for the United States

	%Δ1975-2001		%Δ1977-2000	
	Paid Workers 20-64 (120 cells)			
Efficiency Units	137.4		113.67	
hours	72.83		60.94	
BLS	94.31		79.86	
Fixed Weight	94.56		80.21	
	Skilled	Unskilled	Skilled	Unskilled
Efficiency Units	309.65	76.1	253.99	62.78
hours	173.65	48.52	145.82	40.16
Fixed Weight	184	59.17	152.65	50.77

Notes: See the Appendix for cell definitions.

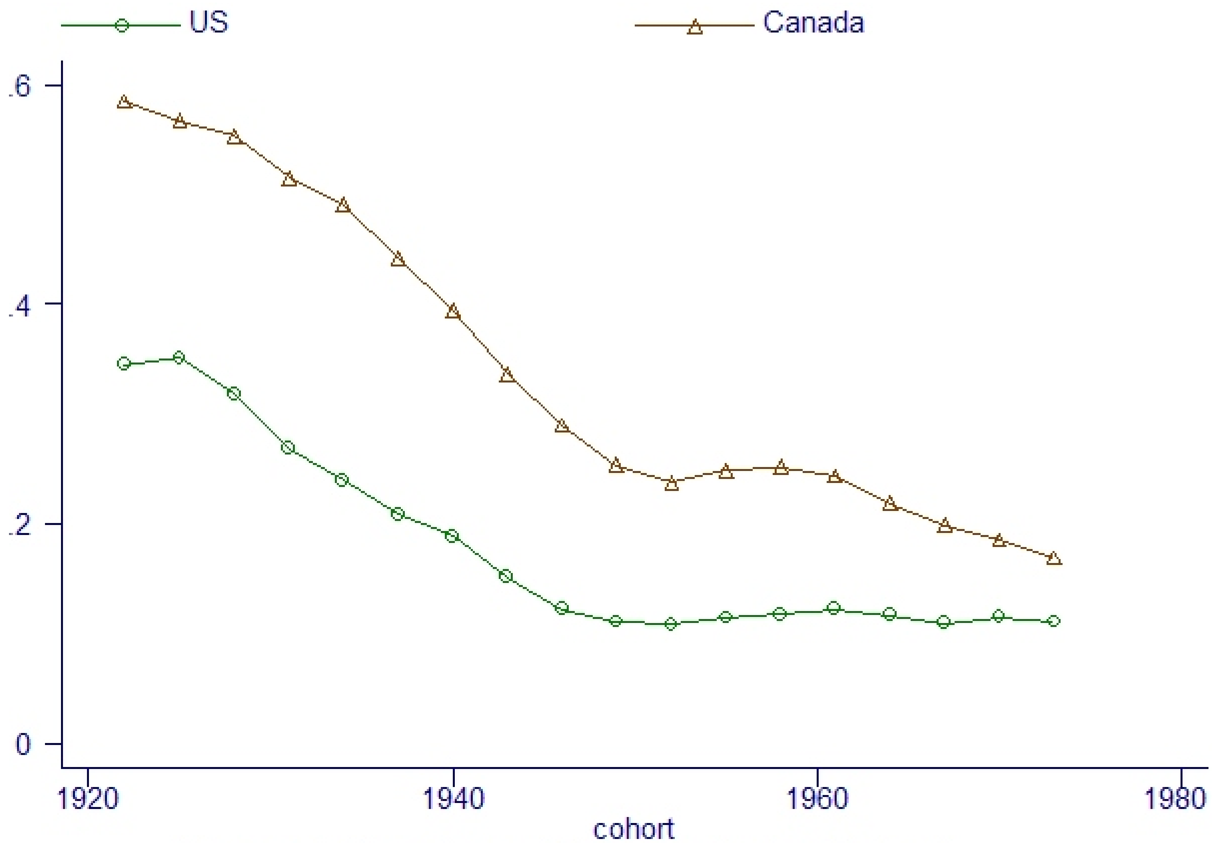

Figure 1: Fraction of Dropouts by Cohort

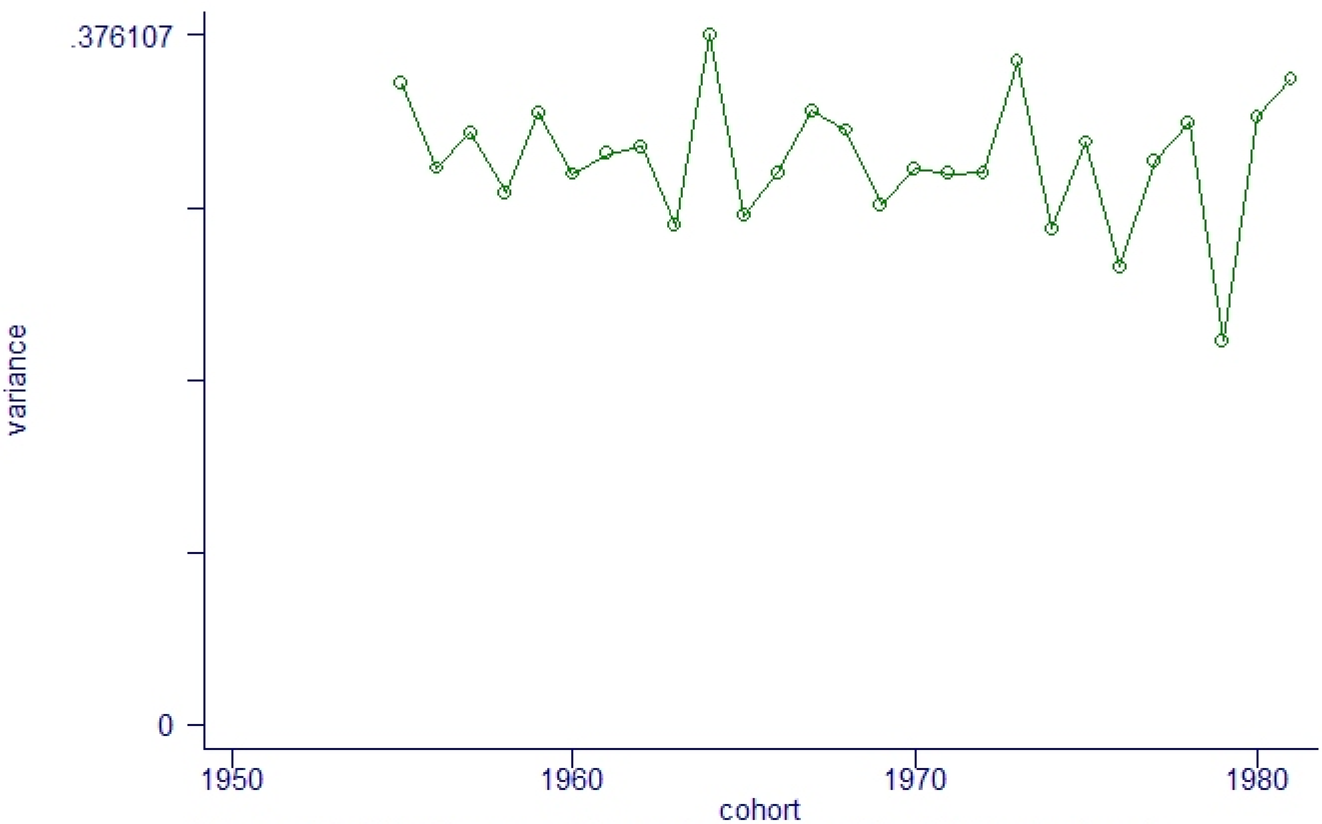

Figure 2: Variance of Log Earnings by Birth Cohort

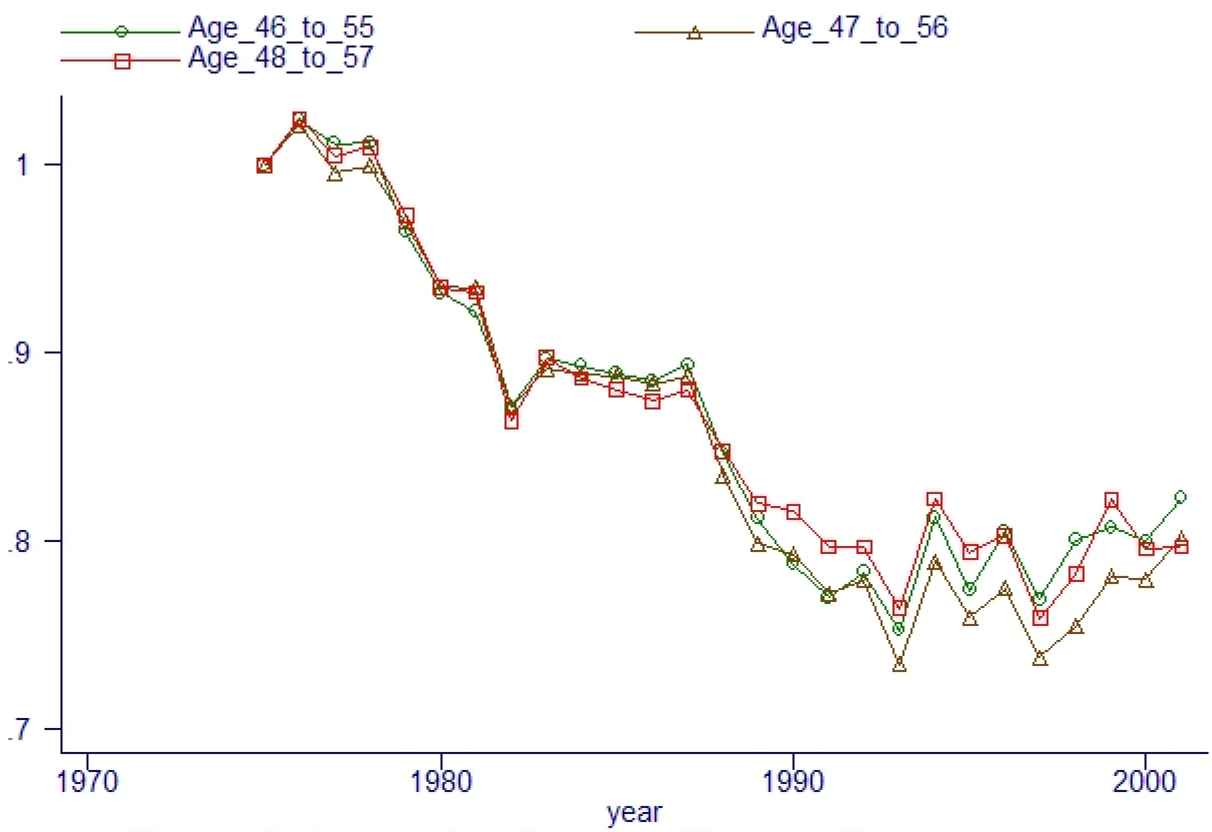

Figure 3: Alternative Dropout Flatspot Regions

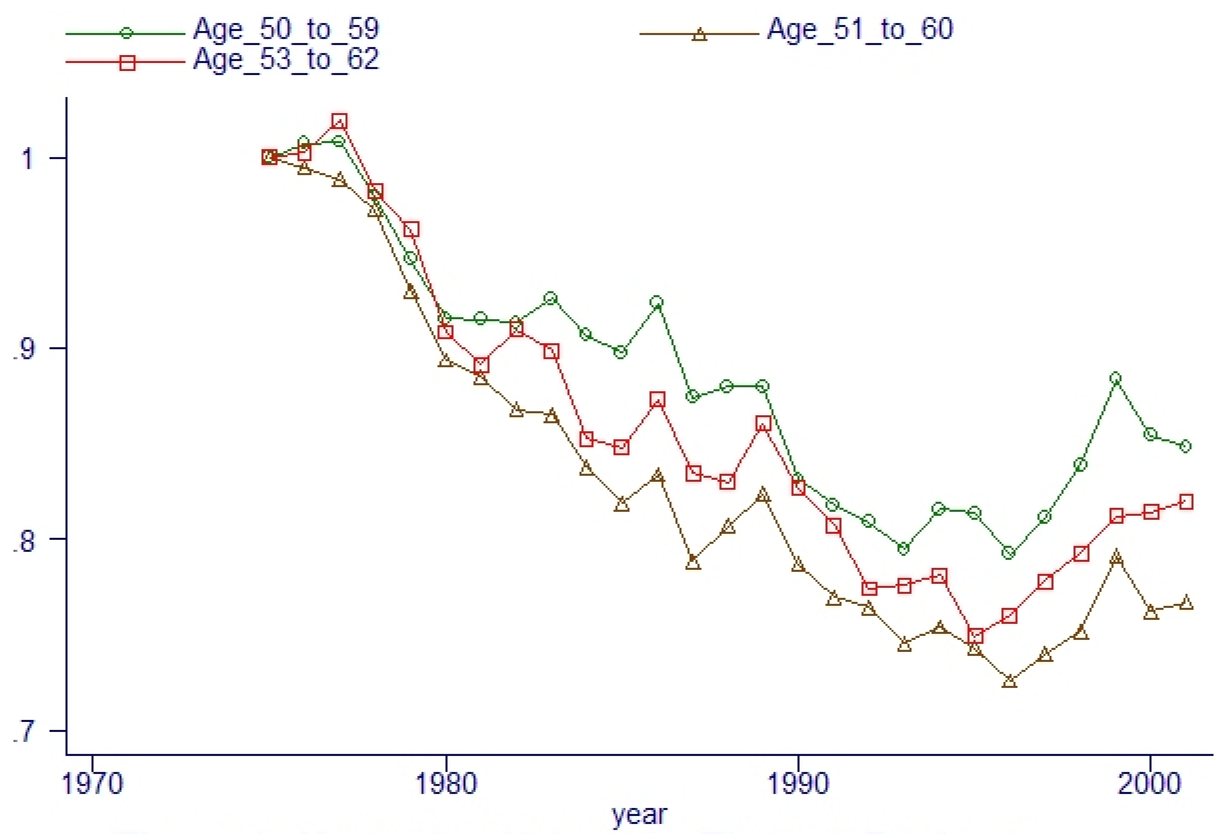

Figure 4: Alternative University Flatspot Regions

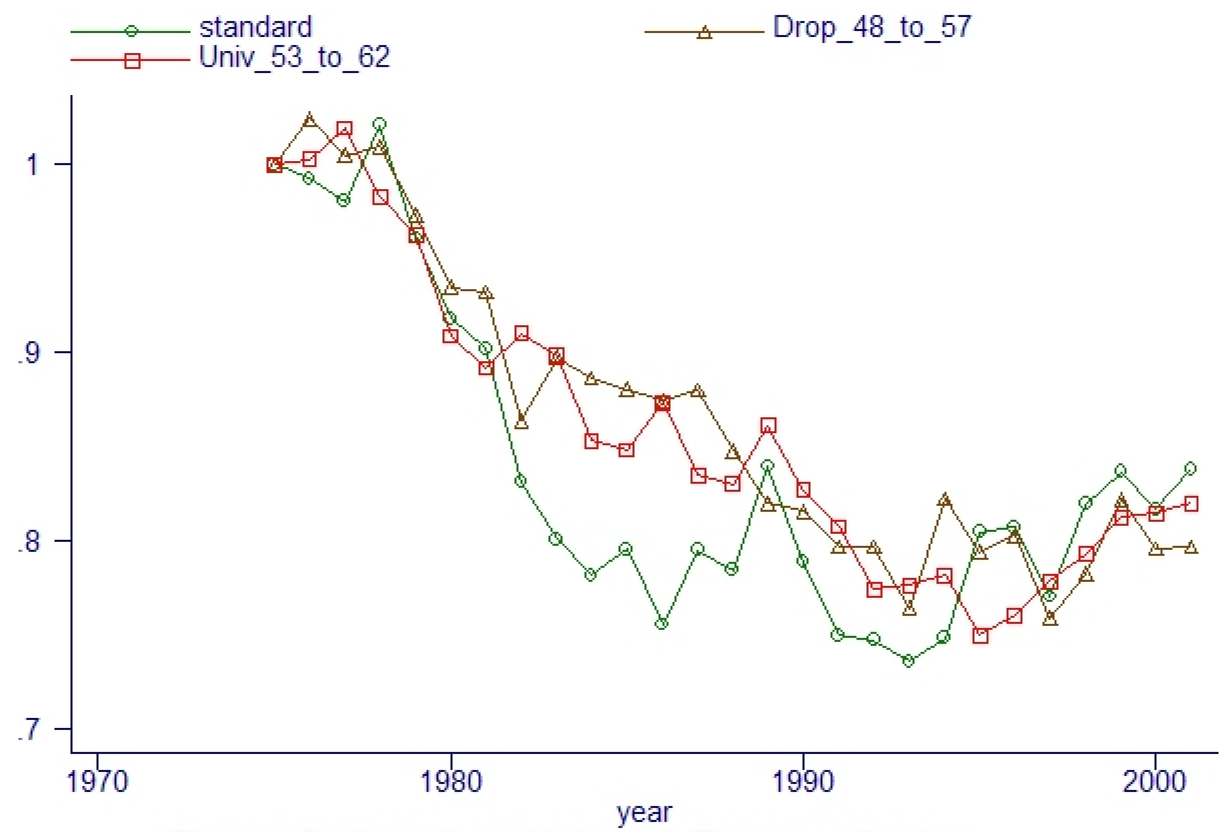

Figure 5: Standard Unit and Flatspot Series

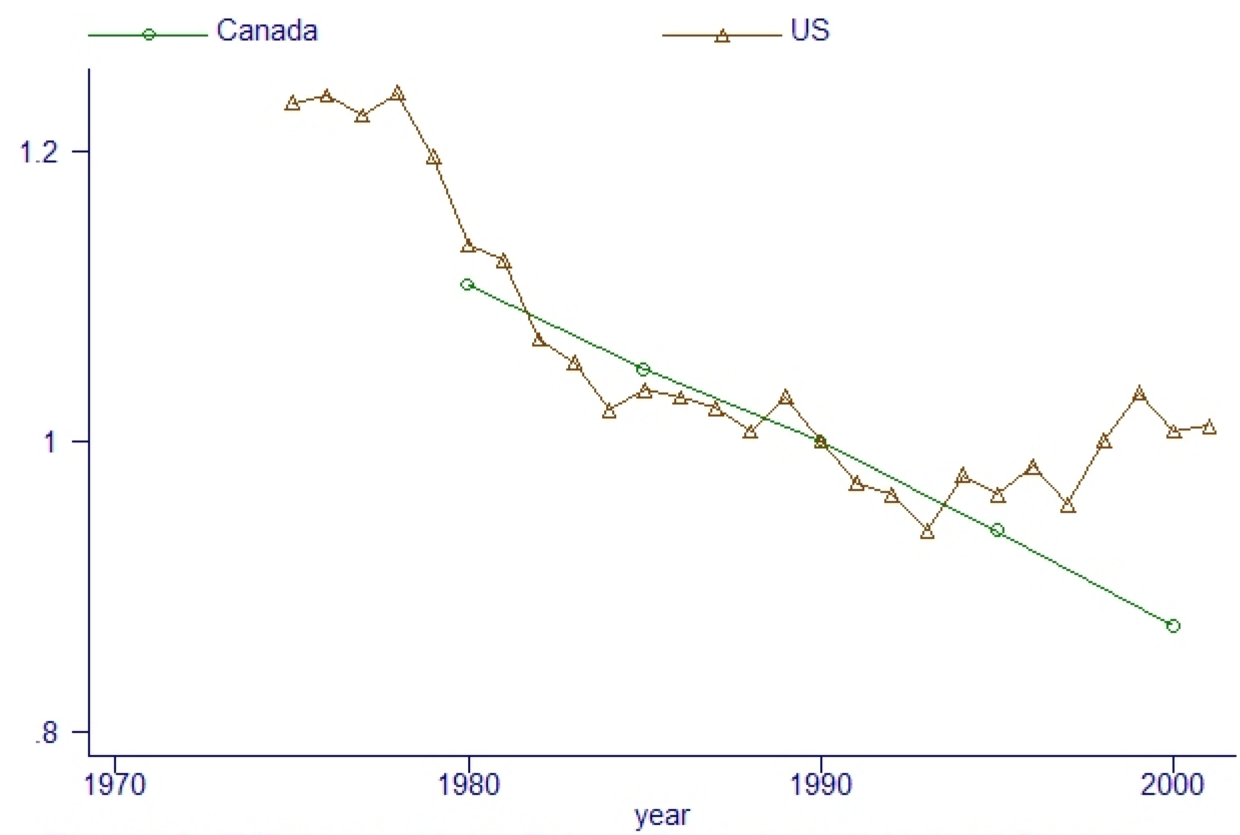

Figure 6: Efficiency Units Price: Canada and United States

APPENDIX

1. Construction of the Education Groups for Canada

The Canadian censuses for 1981-2001 have a consistent "highest level of schooling" variable that has three broad groups, "elementary and secondary" (ESS), "Other non-university" (ONU) and "university" (UNIV) with the following subdivisions:

1	ESS: less than grade 5
2	ESS: grades 5-8
3	ESS: grades 9-13
4	ESS: Secondary graduation certificate
5	ESS: trades certificate/diploma
6	ONU: w/o certificate/diploma
7	ONU: trades certificate/diploma
8	ONU: other non-university certificate/diploma
9	UNIV: w/o certificate/diploma/degree
10	UNIV: with certificate/diploma
11	UNIV : BA or higher

The three groups used in the main analysis in the paper are as follows. The first 3 levels of ESS have no secondary school graduation certificate or equivalent. These are the "dropout" group. However, it should be noted that there are also individuals in levels 5-8 without a secondary school graduation certificate or equivalent. The levels 4-10 are the "other" group. Level 11 is the BA degree or higher group.

2. Discrimination and Female Efficiency Units

Calculation of efficiency units for females depends on whether the male-female wage differential is due to human capital differences or employer discrimination. The differential has narrowed over the 1975 to 2001 period, either because discrimination decreased, or because female human capital relative to males, increased within cells. In the latter case, female human capital may have been less market oriented in the earlier data period, when the female participation rate was low.

The estimated price series were obtained from male samples. If the male-female differences are all human capital differences, the same price series applies to females, and males and females with the same wage have the same amount of human capital. This assumption was used as the benchmark for the quantity estimates in section 6. If the male female differences are due to discrimination, the efficiency units reported for females (and hence the totals) should be adjusted downward. The simplest case is where employers have the same discrimination coefficient. In that case, the psychic cost of employing a female efficiency unit will exactly offset in the wage. Thus, the “total” price for a female efficiency unit to an employer will be the same as that for a male efficiency unit. However, while the male efficiency units follow from dividing the total expenditure on males by this price, the female efficiency units do not.

Suppose the dollar price λ_m is paid for a standard male unit and λ_f for the same level of human capital for a female, with the additional psychic cost of $(\lambda_m - \lambda_f)$ also paid by the employer of the female due to discrimination. Female efficiency units then follow from dividing total dollar payments to females by λ_f. The benchmark procedure in Section 6 will under-estimate the female efficiency units in any period by the percentage difference between λ_m and λ_f in the period. Thus if discrimination falls over time, the growth in female efficiency units over the period will be over-estimated.

3. Cell Definitions Used in the Composition Adjusted Series

The BLS and Jorgenson series, based on chained weighted rates of growth different workers hours, and the fixed weight series that compute weighted aggregates of hours of different workers, use cells based on demographic and other characteristics of the workers such as age, education and sex. The analysis in Section 6 uses the same cell definitions for all composition adjusted series. These consist of 120 cells obtained from the four education levels defined in Section 3, by fifteen 3-year age categories from 20 to 64, by males and females. Experimentation with cell definition and coverage indicates that the results are insensitive to the precise cell definitions.