A Production Model with Age and Vintage Efficiency Adjustment of U. S. Market Hours, 1975-2013

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The genesis of this paper came from an interest in including human capital stocks in a production model, followed by a concern about mismatches, accounting identity violations, and inconsistent treatment of inputs. These considerations led to a decision to recommend age and vintage efficiency adjustment of hours.

Production models can take a variety of forms, but frequently there is a mismatch between inputs or between inputs and output or an inconsistency in treatment between inputs, which impacts on productivity estimates, as well as sometimes an accounting identity problem. This potential mismatch was recognized in Fraumeni (2018). Typically in a value-added production model, GDP is the output measure. Inputs take a variety of forms. Capital is often represented by capital stock, but sometimes by capital service flows. Labor is often represented by the number of workers or by those in the labor force, but sometimes by labor services or hours worked. These input choices are often dictated by the available data, however, mixing stocks with flows creates a mismatch in most cases, which is a concern if researchers want to estimate productivity. GDP is a flow, capital stocks are a stock as are the number of workers or those in the labor force as the hours worked by the latter two can differ. Flows are the output or input to a production process over a set period (say a year); stocks are the input to a production process over a longer period of time (say several years). In addition to the mismatch created when flows and stocks are used in a production model, the basic accounting identity that the sum of nominal inputs must equal the nominal value of output frequently is sometimes not maintained. There seemingly is an inconsistency when physical stocks are adjusted for efficiency as these assets age, hours worked are not as workers age.[1] Although there may well be a correlation between stocks and flows and efficiency-adjusted physical stocks and different forms of labor input as represented in an econometric model, the underlying premise of a production model is violated with a mismatch or an inconsistency.

Interest in this mismatch and inconsistency arose from a desire to measure human capital productivity or total factor productivity (TFP) when human capital is a stock, such as that in Jorgenson-Fraumeni (J-F). The term “human capital” is applied in a variety of research contexts. Sometimes when education is a component of a production model, when entered separately or as a composition or quality adjustment to labor input, the term is used. In this paper, the term human capital refers only to a measure that has current and future flows as a physical capital stock does, for example from structures or equipment. This definition allows a focus on productivity estimation highlighting stock and flow mismatches and physical stock and hours inconsistencies, and discussing the measurement problems, exacerbated by lack of information, associated with vintage effects.

There are four conclusions of the methodological investigations in this paper. The first is that efficiency adjusted current hours should be utilized in production models that estimate total factor productivity TFP. The efficiency adjustment should be of two types: efficiency variations as individuals age and to recognize vintage effects. The second conclusion is that more research is needed to identify both types of efficiency effects, particularly vintage effects across all hours worked. The third conclusion is that a labor input index of current adjusted hours should be the labor input measure in such a production model rather than an index of Fraumeni lifetime

[1] In this paper, the term physical stocks refers to physical and intangible stocks, the latter such as R&D.

adjusted hours human capital stock or J-F human capital stock, to avoid a greater likelihood of a violation of the requirement that the quality of these hours be constant over time, particularly to avoid problems with unrecognized future vintage effects. However, the best human capital companion measure to a production model with efficiency adjusted current hours and TFP is Fraumeni lifetime adjusted hours human capital stock. The last conclusion is that much more research is needed to update and refine the efficiency adjustments of physical capital stock. Many service lives and the shape of their age-efficiency functions are dated, and rarely differ by vintage; this probably impacts on all methodologies whether they be geometric (e.g., the US Bureau of Economic Analysis) or hyperbolic (e.g., the Australian Bureau of Statistics and the U.S. Bureau of Labor Statistics).

TFP results in this paper are only suggestive because of issues with the underlying data, but is hoped that a consistent data base can be constructed by someone in the future to estimate TFP, however, the categories of over time country representative data may not be very detailed .

Much empirical work is needed.

Cobb-Douglas Production Models

A Cobb-Douglas production function is commonly used in research, particularly when a large number of countries are being compared. Casselli (2005), Hall and Jones (1999), and Mankiw, Romer, and Weil (1992) are frequently cited.

Casselli modifies the Hall and Jones production model. Casselli's basic production function is:

Equation (1) $Y=AK^{\alpha}(Lh)^{1-\alpha}$, where Y is GDP, A is the efficiency or TFP factor, K is the aggregate capital stock, and (Lh) is the quality adjusted labor input. Barro-Lee is the source for the quality adjusted labor input component which is set equal to the average educational attainment of those aged 25 and over.

Mankiw, Romer and Weil begin with a standard Solow (1956, 1959) Cobb-Douglas model. They conclude that steady state income per capita can be represented by:

Equation (2) $Y/L=\ln(A(0))+gt+(\alpha/(1-\alpha))\ln(s)-(\alpha/(1-\alpha))\ln(n+g+\delta)$,

where Y is GDP, L is the working age population aged 15-64, A(0) is the technical change term, s is that average share of real investment in real GDP, g is the rate of growth of technical changer, n is the rate of growth of L, and δ is the rate of depreciation. In this model, although investment in the share is a flow, it is not equal to the capital input (capital service flow) into production. This formulation is consistent with the purpose of their model as they are explaining income per capita rather than indicating how inputs produce output.

Jones (2014) concentrated on the skill levels of workers. He modifies a labor augmenting Cobb-Douglass production function:

Equation (3) $Y=K^{\alpha}(ALH)^{1-\alpha}$,

by using a different aggregator for H, which he calls the Generalized Division of Labor (GDL) aggregator:

Equation (4) $H=[h_1^{(\theta-1)/\theta}+Z(H_2,H_3,\ldots,H_N)^{(\theta-1)/\theta}]^{\theta/(\theta-1)}$

where θ is the elasticity of substitution between unskilled human capital, H_1, and an aggregation of all other human capital types, $Z(H_2, H_3, \ldots, H_N)$. The GDL does not require that a specific type of aggregator be specified or that the underlying quality of labor be known. As such, it is an ideal aggregator to investigate income differences between countries, for example rich and poor countries as Jones did, but it is not intended to describe production within a country with labor input flows.

In a sources of economic growth analysis production models by Jorgenson and his co-authors, which Jones labels traditional accounting, output and labor and intermediate inputs are measured with flows, with the exception of physical capital input which is measured by a stock index.[2] Contributions to output growth are determined by Törnqvist input indexes; output is also measured with a Törnqvist index.[3]

Jorgenson-Fraumeni Human Capital

J-F human capital is a stock, represented by the lifetime income of individuals discounted to the present and allowed to grow at a specific rate. The early human capital papers which established the methodology were co-authored by Jorgenson and Fraumeni (1989, 1992a, 1992b); subsequently publications were co-authored by Christian (2016), Fraumeni and Christian (2019), and Fraumeni, Christian, and Samuels (2017, 2021). When the quantity of physical capital input is measured with a Törnqvist index of physical capital stock with average nominal shares of current capital service flows (capital input) as weights, the result is identical to one with the quantity of capital input if the quality of the physical stocks are constant.[4] The qualities vary by type of physical capital stock and transform physical capital stocks into a flow of capital

[2] See for example chapter 9 of Jorgenson, Gollop, and Fraumeni (1987).
[3] Jorgenson prefers the term translog to the term Törnqvist to describe the same index.
[4] Quality in J-F is measured by the quantity of the human capital stock per capita; in the Fraumeni measures presented later in this paper it is equal to the quantity of the human capital stock per adjusted hour for the stock version and the quantity of labor input per adjusted hour for the current labor input version. In Inklaar and Papakonstantinou (2020) it is measured by the quantity of labor input (labor services) per hour for current labor input.

services.[5] The quantity of physical capital stocks so derived are not mismatched with the flow of labor input because of this characteristic. Without the constant quality assumption, which is not necessarily assumed by the Cobb-Douglas models described above, a mismatch occurs. However, there is a different type of mismatch between capital input, labor input and J-F human capital stocks even if the analysis is restricted to market human capital as the logarithmic rate of growth of workers is weighted by average lifetime income shares, which include current and future earnings. This different type of a mismatch does not occur if the constant quality assumption is justified when a Törnqvist index of physical capital stocks are in a production model, with the weights average nominal current capital input shares.

In this paper, the focus will be on market human capital to fit into a market production model, accordingly the following describes market J-F human capital.

In the J-F formulation, from age 15 through 34, individuals may work at the same time as going to school. From age 35, only work is possible.

Nominal market human capital stock measures, per capita human capital in year y for a person of sex s, age a, and years of education e for those who might attend school and engage in market work is equal to:

Equation (5) $$i_{y,s,a,e} = ymi_{y,s,a,e} + (1+\rho)^{-1}(1+g)sr_{y,s,a+1}[senr_{y,s,a,e}i_{y,s,a+1,e+1} + (1 - senr_{y,s,a,e})i_{y,s,a+1,e}]$$

where

s = sex (male or female);

a = age (15 to 34);

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[5] See p. 131 of Jorgenson, Gollop, and Fraumeni (1987).

e = years of education (0 to 18);

$i_{y,s,a,e}$ = per capita lifetime income in year y of persons of sex s, age a, and years of education e;

$yi_{y,s,a,e}$ = per capita yearly income in year y of persons of sex s, age a, and years of education e;

$sr_{y,s,a}$ = survival rate in year y of persons of sex s from age a-1 to age a;

ρ = discount rate;

g = real income growth rate;

$senr_{y,s,a,e}$ = school enrollment rate in year y of persons of sex s, age a, and years of education e, which is equal to zero from age 35.

For those aged 35 through 79, this equation simplifies to:

Equation (6) $i_{y,s,a,e} = ymi_{y,s,a,e} + (1+\rho)^{-1}(1+g)sr_{y,s,a+1}i_{y,s,a+1,e}]$

For persons aged 80 and older, per capita human capital is equal to:

Equation (7) $i_{y,s,80+,e} = [1 - (1+\rho)^{-1}(1+g)sr_{y,s,81+}]^{-1}yi_{y,s,80+,e}$.

which is the sum of an infinite series, and is equal to expected lifetime income given a yearly income $yi_{y,s,80+,e}$ that increases at an annual rate of g, a constant rate of survival $sr_{y,s,81+}$, and a discount rate ρ.

Total human capital is $i_{y,s,a,e}$ multiplied by the population with hours in each category, $pcount_{y,s,a,e}$. Nominal investment in births is the expected lifetime income of a newborn. Investment in education is the difference in lifetime income between an individual with the same characteristics and another, with one currently enrolled in school and the other not so. Depreciation from aging and deaths is deducted from gross investment. The human capital consumption component values time not spent in sleep, personal maintenance, education, or work at the market (opportunity cost) wage. There are some methodology timing differences in the 2016 Christian and 2019 Fraumeni and Christian paper, versus the 2017 and 2021 Fraumeni, Christian, and Samuels paper and the much earlier Jorgenson and Fraumeni papers.

Human capital quantities in the Jorgenson and Fraumeni co-authored papers were measured with Törnqvist indexes; in the papers co-authored by Christian or Fraumeni, Christian and Samuels or Fraumeni and Christian they are measured with Fisher indexes, with the exception of quantities such as net investment, which can include negative components. Aggregates that include human capital components are computed with Törnqvist indexes. Unless movements in the index components are large, Fisher and Törnqvist indexes result in very similar time series. Prices are implicitly determined from the nominal values and the quantities.[6] Fisher indexes are a geometric average of Paasche and Laspeyres indexes. As previously noted, with a Törnqvist index, the weights applied to the logarithmic rate of growth of the number of workers, are average shares of nominal lifetime income.

Previous Estimates of Productivity with J-F Human Capital for the United States

Previous estimates of TFP including J-F total (market plus nonmarket) human capital successfully dealt with the accounting identity (Fraumeni, Christian and Samuels 2015 and 2021, and Fraumeni and Christian 2017).[7] This was done by adding the value of nominal J-F lifetime

[6] Quantities such as net investment, which can include negative components, are created using additive aggregation.
[7] In a November 22,2018 presentation at a ESCoE human capital conference in London a market only TFP estimate was presented, but the methodology mimicked that in the published total TFP methodology with J-F human capital market and nonmarket inputs and outputs.

human capital consumption and investment flows to labor input to create an augmented output.[8] Investment in education and births and time in household production and leisure – the latter the consumption component of human capital – are part of the index of augmented output, as are these components in the form of labor input part of augmented labor input. Because the accounting identity is maintained and the nominal value and the quantities of investment in human capital and time in household production and leisure are entered on the output and input side, it was implicitly assumed in the publications listed above that there is no TFP associated with human capital. TFP with and without human capital differ because the average nominal share weights on the rate of growth on the other output and input components become much smaller when human capital is added to the production model. The growth rates of the human capital stock flow components are identical on the output and input side of the model. Table 1 shows that the impact of including human capital on average nominal shares in the most recent publication is very significant as is the effect on TFP.

[8] However, as J-F human capital stock includes current labor income as does market labor input, the nominal dollar value of gross investment was too large.

Table 1: Impact of Including Human Capital Stock on Average Nominal Shares and Total Factor Productivity (TFP), 1949-2013					
	Average Nominal Shares[9]		**Average Nominal Shares**[10]	**TFP**	
Consumption with HC	.366	**Capital Input with HC**	.089	**With HC**	.18
Consumption without HC	.670	**Capital Input without HC**	.425		
Investment with HC	.634	**Labor Input with HC**	.911	**Without HC**	1.02
Investment without HC	.330	**Labor Input without HC**	.575		

Source: Fraumeni, Christian, and Samuels (2021) and the Christian data underlying that paper.

[9] Consumption with human capital includes consumption in Gross Private Domestic Product (GPDP) and time in household production and leisure; the latter is a nonmarket human capital component. Investment with human capital includes investment in GPDP and both market and nonmarket human capital investment. See Fraumeni, Christian, and Samuels (2021).

[10] Capital input includes GPDP capital input as defined in Fraumeni, Christian, and Samuels (2021). Labor input with human capital includes time in household production and leisure and both market and nonmarket human capital investment as labor input (Fraumeni, Christian, and Samuels, 2021).

Revised Production Model with Fraumeni Market Lifetime Hours Human Capital for the United States

It is simple to maintain the nominal dollar accounting identity; the challenges are to remedy the stock and flow mismatches and to deal with the input inconsistencies and vintage effects.

The proposed solution to remedy the stock and flow mismatches is to modify J-F lifetime income methodology by measuring market human capital with a stock of current and future market hours input. Both current and future hours are part of the stock. Accordingly, market human capital enters into the production model through a Törnqvist index with the average shares of the current labor input in total input weighting the logarithmic growth rate of the hours stock. In any year, say 2000, the quantity of the Fraumeni market lifetime hours stock is a summation of future hours expected to be worked by gender, age, and education based on hours worked of those older in 2000. Although individuals younger than 35 may complete an additional year of education in the future, the current level of education was maintained in the summation of expected future hours worked. Future education is an investment; substantial physical capital additions, renovations and reconstruction are also considered an investment. The use of hours for those older in a given year is similar to how nominal lifetime income is constructed as nominal total lifetime income for any year is the summation of nominal lifetime income of those older in that year, but with a rate of growth and a discount rate factored in as to adjust for nominal values. Such an adjustment is not needed for hours as hours are a quantity. Once these new constructs are created, with an index of output and input, TFP can be determined, however vintage effects can impact on the accuracy of the TFP estimates because use of either physical or human capital stocks require a constant quality assumption, even with rates of growth weighted by nominal physical or human capital average shares.

The basis for current and future lifetime labor input are the hours, compensation and educational attainment Christian data underlying Christian (2016). With this data, Törnqvist indexes can be created with current earnings as the basis for the average nominal shares. The total number of categories (by gender, age, and education level) from the Current Population Survey (CPS) data base which have nonzero hours to allow for the creation of an hours stock is over 2,000 for each year.[11] As previously noted, both market physical capital and human capital input from stock quantities rely on the assumption that the quality of the input by category is constant over time, an assumption that is violated in the presence of any significant vintage effects. Both physical and human capital stocks in all likelihood are mismeasured, the former because service lives, depreciation rates and efficiency-age shapes are rarely updated, thereby missing possible vintage effects; human capital stocks because of the lack of efficiency adjustment of hours and the possible presence of vintage effects.

A first step in construction Fraumeni adjusted hours measures before estimating TFP is to remove the inconsistency between physical and human capital by efficiency adjusting hours worked as individuals age. The Programme for International Assessment of Adult Competencies (PIAAC - OECD, 2019) results support the notion that the efficiency of hours worked by individuals vary by age.[12] As a starting point, the efficiency of hours worked will be allowed to vary by age based on the PIAAC results. One difference from physical stocks which decline in efficiency as assets age, hours will be allowed to increase in efficiency as younger workers age,

[11] The March supplement to the Current Population Survey (CPS) is the source for the data on hours worked and earnings and the October CPS supplement is the primary source for the data on educational attainment.

[12] See Figure 9 of OECD 2019 which shows literacy and numeracy scores of individuals by a representative sample of age groups who participated in PIAAC both in 2012-2104 and in 2017. This figure shows that differences occurred as individuals aged with results from participants in the 2012-4 and 2017 U.S. surveys. The U.S. is the only country that has thus far participated in two rounds of the survey. The target population for PIAAC is the non-institutionalized population, aged 16 to 65 years, residing in the country at the time of data collection, irrespective of nationality, citizenship or language status.

before hours efficiency will be allowed to decline in efficiency, at least through age group 55 and over. Table 2 shows the PIAAC results and the adjustments to hours based on the 2012 PIAAC.[13] This will not eliminate the possible vintage effects to which Inklaar and Papakonstantinou (2020) and Bowlus and Robinson (2012) refer, but it will recognize that efficiencies differ by age.[14] [15] PIAAC U.S. literacy and numeracy age efficiency profiles for those who took part in both the 2012/2014 and 2017 PIAAC do not reveal vintage effects, but they may occur over different time periods.[16] Note that as shown in Table 2 the problem solving skill is the only one that monotonically declines by age group. In addition, across all skills, the largest percentage decrease is between those aged 35-44 and 45-54.

Table 2: Hours Efficiency Adjustment Based on 2012 PIAAC

	Age Groups				
Skill	16-24	25-34	35-44	45-54	55 & over
Literacy	272	275	273	266	263
Numeracy	249	260	258	250	247
Problem Solving in Technology Rich Environments	285	283	279	271	267
Average Score	269	273	270	262	259
Hours Efficiency Adjustment	.985	1.000	.990	.960	.950

[13] Although Figure 9 included a breakout of the 55 and over age group into 55-59 and 60-64 age groups, this breakout is not used in this paper's analysis under the assumption that PIAAC statisticians were less comfortable with a more detailed age breakout than with the 55 and over age breakout as the US report did not show the more detailed age breakouts.

[14] Inklaar and Papakonstantinou (2020, p. 24) write in their conclusions section that a standard assumption used in growth accounting: "an hour worked by a worker of a given type,...., represents a constant amount of labor services per hour worked over time. Yet if there are vintage effects, this assumption may be violated."

[15] Inklaar and Papakonstantinou (2020) conclude that the vintage effects are important in the U.S. between 1975 and 2014, a time period which is almost identical to that to be covered in the proposed paper. Hudomiet and Willis (2021) analyze how computerization affected the labor market outcomes of older workers between 1984 and 2017. Bowlus and Robinson (2012, p. 3514) conclude that "A large part of the increase in the quality of the labor input is not due to composition changes but instead to technological change in human capital production and changes in the optimal accumulation over the life-cycle, especially for females. Since most attempts at adjusting the labor input for quality changes used to estimate MFP only deal with composition, they cannot capture a large part of the quality change."

[16] See Figure 9 of OECD 2019. This report stated that the problem solving in technology rich environments average score marginally improved between 2012/2014 and 2107.

Because efficiency is set to 1.0 in the age group (25-34) with the highest average skill score, adjusted hours are lower than unadjusted hours for all other age groups. Figure 1 shows the average percentage decrease between unadjusted and adjusted hours. The percentage reduction drops from 2.06 percent in 1975, to the smallest reduction of 1.75 percent in 1987, before increasing to 2.41 percent in 2013. This reduction is driven by the size of the working population, the hours the younger, prime age, and older work, and the increasing labor force participation of women. Most noticeably, the workforce has aged as the post-World War II baby-boomers aged. The boomer birth rate peaked in 1947, but individuals born between mid-1946 and mid-1964 are considered baby-boomers.[17] [18]

The following three figures are unadjusted hours pyramids with information on the percentage of total hours worked by gender. The percentages for males are shown as negative numbers to facilitate construction of the pyramids; in fact they are all positive and equal to the absolute value of the negative figure shown. The sum of all percentages in a pyramid for a year is 100 percent. The pyramids demonstrate the changes in hours worked in 1975 and 2013 and in 1987, the year of the smallest efficiency reduction by age.

[17] National Office of Vital Statistics (1950), Table Y, p. XIX.
[18] Colby and Ortman (2014), p. 2.

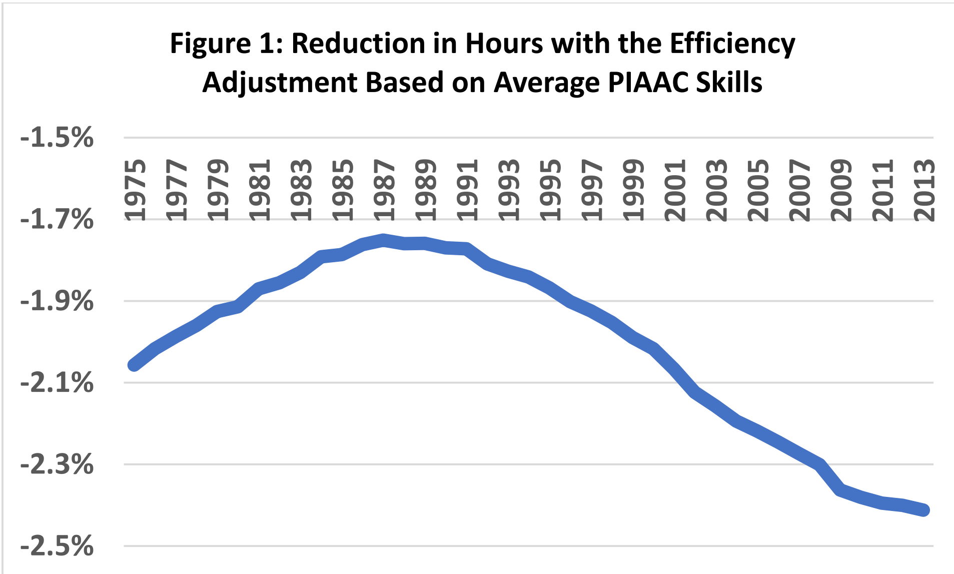


Figure 1: Reduction in Hours with the Efficiency Adjustment Based on Average PIAAC Skills
-1.5%
-1.7%
-1.9%
-2.1%
-2.3%
-2.5%
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013

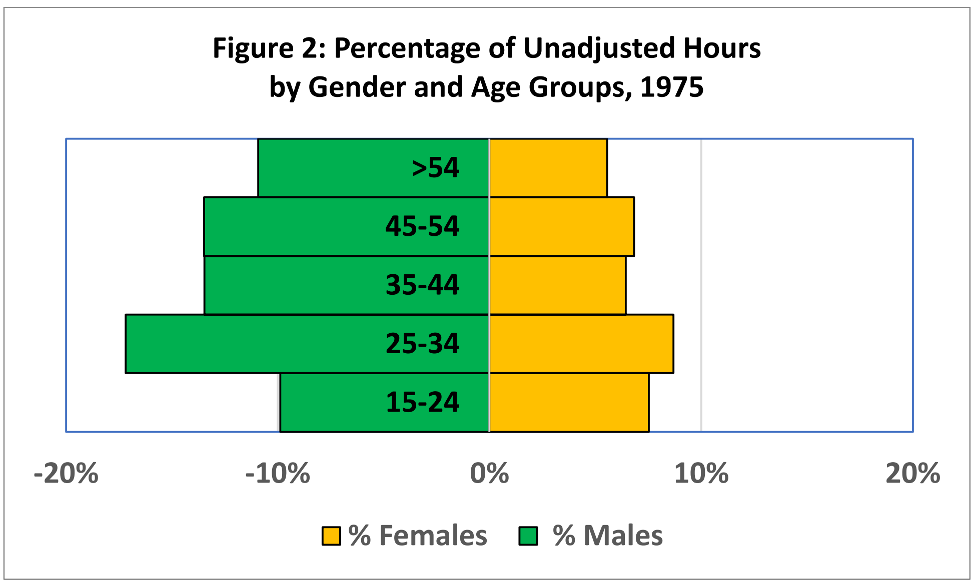
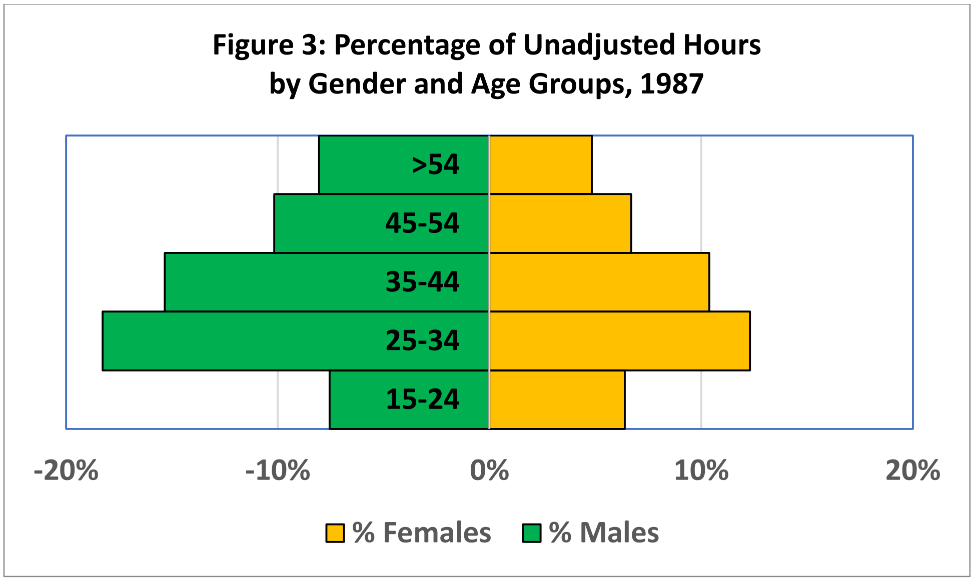
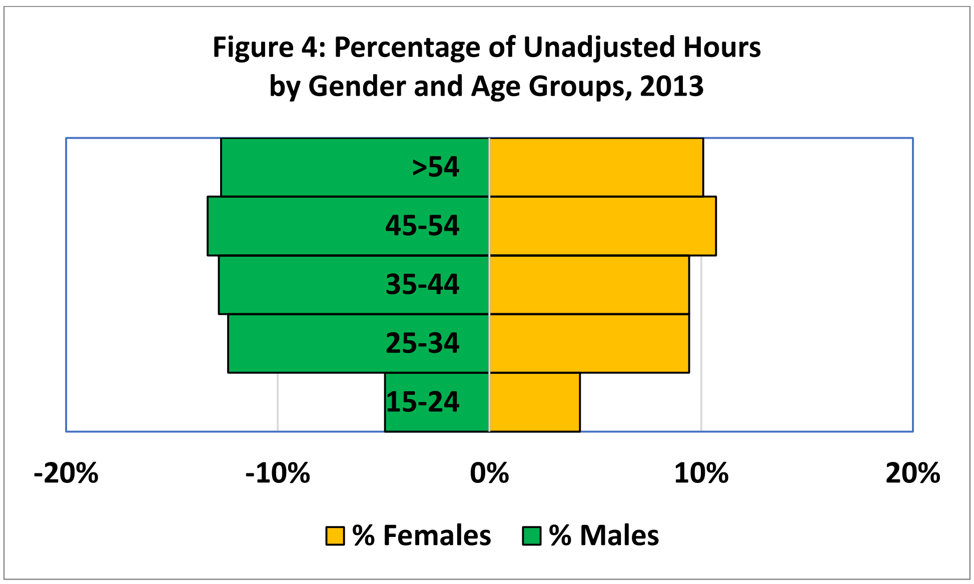


Figure 2: Percentage of Unadjusted Hours by Gender and Age Groups, 1975
>54
45-54
35-44
25-34
15-24
-20%
-10%
0%
10%
20%
% Females
% Males





The shapes of these unadjusted hours pyramids show the changes over time. 1987 is the year in which the percent of hours worked by individuals with the highest average PIAAC skill rating, those aged 25-34, is at its maximum of the whole period, 1975-2013. With a pyramid shape on the youngest age group base (Figure 3), it is not surprising that the percentage difference between unadjusted and adjusted hours is the smallest. Although the 25-34 block is the largest of all blocks in 1975 (Figure 2), the differences in the block widths is much less than in the 1987 pyramid. In 2013 (Figure 4), the block widths for all age groups except for that of those 15-24 is most similar, reflecting in part the aging of the baby-boomers. In addition, between 1975 and 2013, the percentage point difference between hours worked by males and that by females for all age groups dropped by at least half, reflecting the higher labor female force participation rates by 2013. For these reasons, the percentage difference between unadjusted and adjusted hours is at its maximum in 2013.

The next figure, figure 5, shows J-F market lifetime income and Fraumeni (F) efficiency adjusted lifetime hours stocks, as well as F efficiency adjusted current hours, all normalized to 1.0 in 1975. Since J-F depends upon logarithmic rates of growth of population and F depends upon logarithmic rates of growth of hours, it is no surprise that the F stock is always above the J-F stock. From 1975-2013, annual male hours grew at about one percent per year and annual female hours grew at about two percent per year, while the population grew at about one percent per year. The figure is normalized to one in 1975 as F lifetime and current hours indexes are both normalized to nominal labor input (earnings) in 2012, but J-F human capital stock is normalized to nominal lifetime income (earnings) in 2012. Without the normalization to one in 1975, the J-F lifetime income index line would be far above either F versions. A sense of the magnitude of the difference is shown in table 2 in the comparisons of average nominal shares in a production model without human capital and one with J-F human capital. F lifetime adjusted hours typically grows at a slower rate than F current hours as the lifetime hours base is so much larger than current hours. J-F lifetime income measures continue to be valuable as they can be directly incorporated into NIPA and SNA-like accounts as they allow estimation of investment, stock revaluation, depreciation, and so forth.

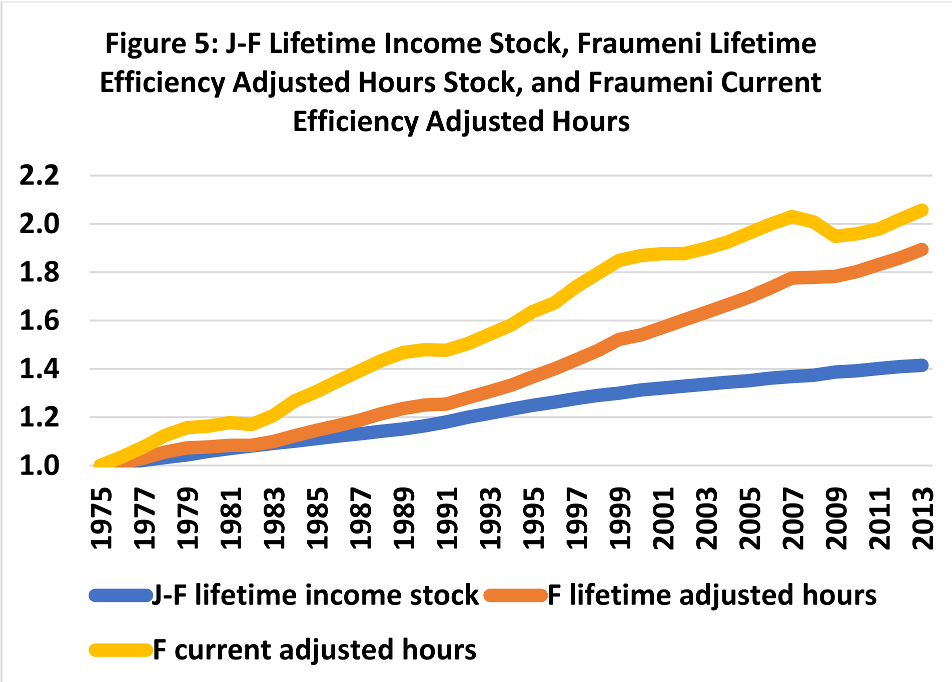


Figure 5: J-F Lifetime Income Stock, Fraumeni Lifetime Efficiency Adjusted Hours Stock, and Fraumeni Current Efficiency Adjusted Hours

Vintage Effects Literature and Estimation Results in a Market Production Model:

The Bowlus and Robinson (2012) and Inklaar and Papakonstantinou (2020) results for the U.S. are central to a possible partial remediation of the vintage effects problem. Inklaar and Papakonstantinou (IP hereafter), followed the methodology of Bowlus and Robinson (BR hereafter), but applied the methodology to compare vintage effects of the U.S. versus six European countries. By looking at a flat spot in high-skilled worker wage profiles, BR attempted to isolate vintage effects. Three categories of male employees were identified for the U.S. by IP: High-skilled workers (those having completed tertiary education), medium-skilled workers (those having completed secondary education) and low-skilled workers (those not having completed secondary education). It was assumed that the flat spot identified in the high-skilled worker wage profiles occurred three years of age earlier for medium-skilled workers and six years earlier for low-skilled workers. IP adopted the BR flat spot range for U.S. high skilled workers. IP's estimates for full-time, full-year workers (FYFT) male workers that were not self-employed indicated that labor services per hour (quality) increased by 25 percent between 1975 and 2015, with most of the increase (19 percent) occurring between 1995 and 2005. For the same FYFT male category of workers, but having medium skills, labor services per hour decreased 10 percent, with most of the decrease occurring between 1975 and 1995 and trending inconsistently subsequently. For the same FYFT male category of workers, but having low skills, labor services per hour decreased substantially doing the same time period as those with medium skills, with a total decline of 20 percent for the whole period (IP, pp. 11-12). By age groups for U.S. high-skilled workers over the period 1995-2005, wages of young workers aged 26-35 increased by 6.2 percent, wages of middle-aged workers aged 36-49 increased by 12.6 percent, and wages of old workers aged 50-59 decreased by 1.2 percent (table 9 of IP).

IP realize that such vintage effects can occur for several reasons: The quality of students, the quality of higher education and changes in workers' human capital production function. It is possible that when more students attend higher education, the average quality of graduates given a constant quality of higher education may decline. IP also note that it is also true that the quality of higher education, through more work relevant and better courses, or the human capital production function, through experience and on-the-job-training, may both improve, so that the net effect is uncertain.

Both BR and IP primarily used median wages for males FTFY. IP note the difficulty of including females because of the changing labor force participation of females during the 1975-2014 time period. IP did conduct sensitivity tests by including all males that worked at least five hours per week for at least five weeks in a year, removing the top and bottom five per cent of wages in the flat spot area, and focusing only on certain industries. The pattern for high-skilled workers is the same as for the baseline FTFY case, however, there is not a clear pattern for the medium-skilled and low-skilled workers. IP concluded that there was "again, no substantial deviation from the baseline results" (IP, p. 17). The sensitivity tests are relevant as the estimates provided later in the paper include all workers with hours, with data from the March CPS supplement and from the October CPS supplement. Both BR and IP's sample is from the March CPS supplement.

Hudomiet and Willis (2021) looked at the impact of computerization, which largely took place in the 80's and 90's, on the labor market situation of older workers. They documented that older workers started using computers later than younger workers until about the early 2010's. They "found that the knowledge gap shortened the working life of older workers, it pushed many full-time workers into part-time jobs, and it lowered their wages." (p. 34) Females, middle-skilled workers, and older workers experienced larger effects than others. Their research documented the existence of computer-related vintage effects. IP note that age-related technological factors may impact particularly younger high-skilled workers (p. 4); the PIAAC problem solving in technology rich environments skill scores by age support this notion.

Experimental Vintage Adjustment for a Market Production Model Based on IP and BR

There are decisions to be made in constructing the experimental vintage efficiency adjustments, given age adjusted efficiency hours: Whether to use labor input based on efficiency age adjusted current hours or labor input based on efficiency age adjusted lifetime hours, whether to incorporate the IP high-skilled age results, and if so, whether to apply them to all (male and female) workers with hours, and regardless of the current or lifetime hours decision, and how to combine the PIAAC and vintage information. To avoid a more likely violation of the constant quality assumption with a stock than with efficiency age adjusted hours, labor input based on efficiency age adjusted current hours is the basis for possible vintage efficiency modifications. It is assumed that an assumption violation is more likely with a stock as a stock has current and future components, with current hours only having a current component. To aid in the worker scope decision, quality (labor input - constructed with a Törnqvist index - per hour) by gender and the three skill categories for all individuals with hours worked with the efficiency age adjusted hours is estimated. These categories are the same as used in IP for FTFY males. The Christian data set does not allow applying the vintage effects only to hours of FTFY males with an efficiency adjustment, as it only includes information on average hours worked by age and education category, without further detail.

Figure 6 shows that it makes a difference if efficiency age adjusted current hours rather than lifetime efficiency age adjusted hours are the basis for estimation of TFP. These current and lifetime hours calculations are done across all categories when there are positive hours in the base year. There are over 2,000 base year positive hours categories in each year. Categories are by gender, single years of age, and single years of education. Except in 1976 and 1977, the differences in the TFPs are very small until 1985. However, the fluctuations in TFP are similar in all years.

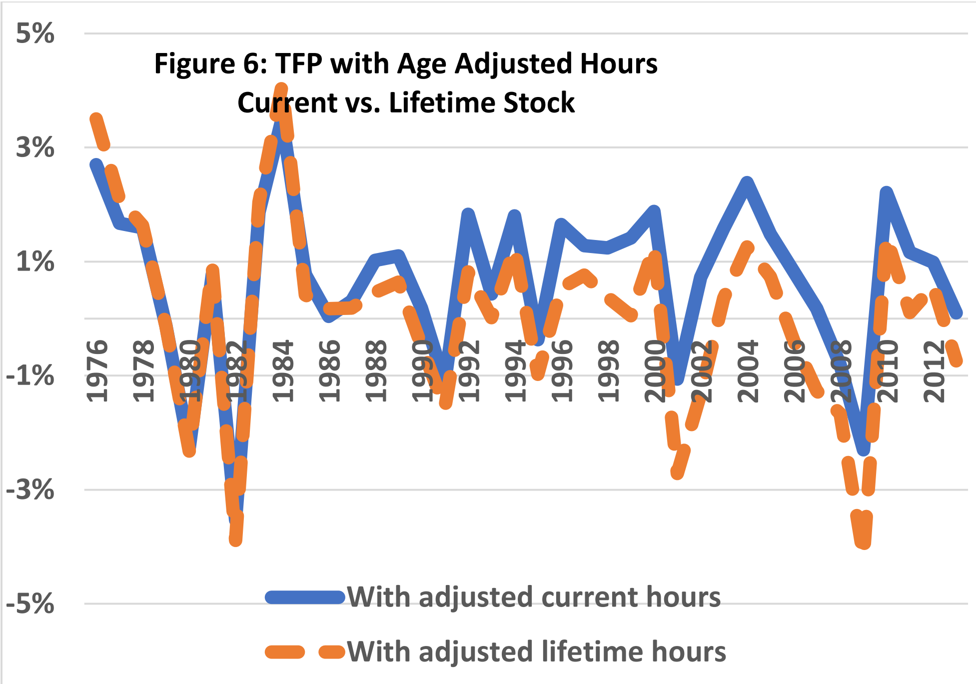
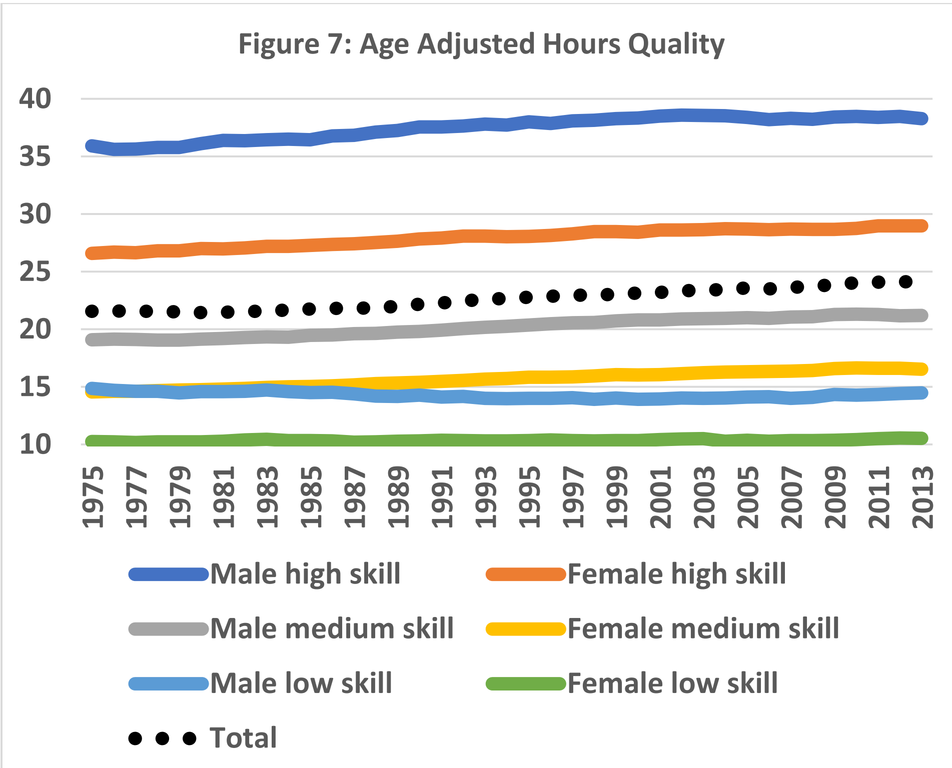
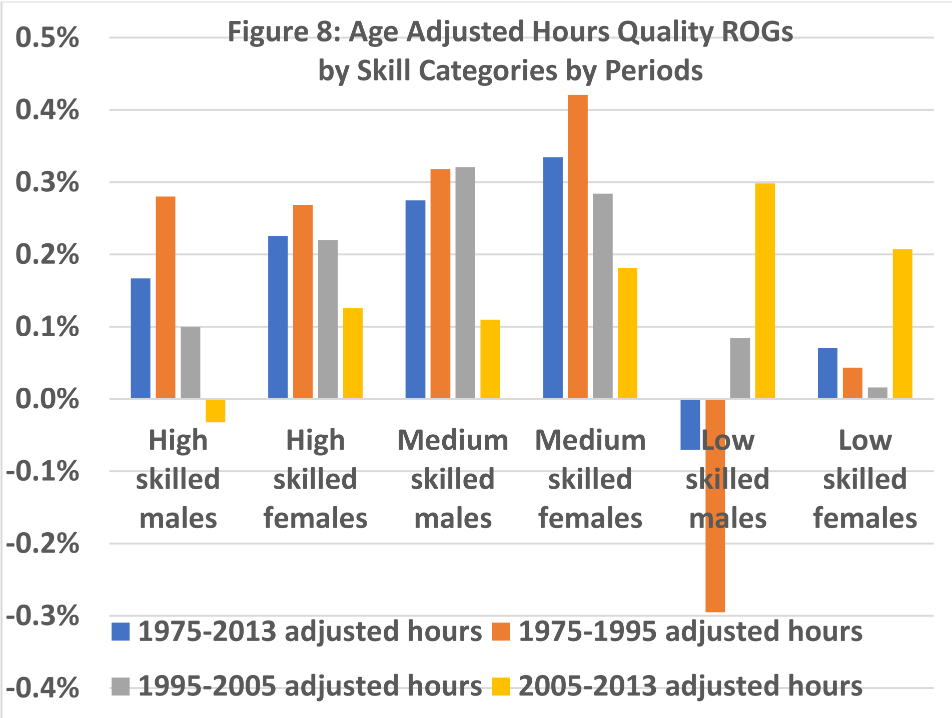


Figure 7 shows the efficiency age adjusted current hours Christian data quality results. Quality or labor input per hour varies significantly by category, but as Figure 8 shows and Figure 7 suggests, the average quality rates of growth for the whole period: 1975-2013 and the three subperiods: 1975-1995, 1995-2005, and 2005-2013, are quite low. Those by gender and skill categories vary from a high in 1975-1995 of .42 percent for medium skilled females to a low in the same subperiod of -.30 percent for low skilled males. The vintage results from IP particularly for FTFY high-skilled males (approximately 1.9 percent on average per year for 1995-2005) differed significantly from these results. Accordingly, the decision was made to not vintage adjust the efficiency age adjusted hours using the IP results. The average quality rates of growth for the overall quality index, computed from the gender and skill Törnqvists, are .30 percent for 1975-2013, .27 percent for 1975-1995, .35 for 1995-2005, and .28 for 2005-2013. This analysis does not indicate which results are correct or that there are no vintage effects for the gender and skill categories, because of different IP's and this paper's worker coverage and possible issues with the Christian data base (e.g., different coverage in the March and October

CPS supplements), therefore no conclusive conclusions can be reached.[19] More research is needed.



[19] A paper recently presented at an IARIW conference with reference to Frazis and Stewart (2004) noted that the more-educated workers in the Consumer Population Survey compared to the American Time Use Survey over-estimated hours worked and less-educated workers under-estimated hours worked (Eldridge, Pabilonia, and Stewart, 2021, p. 9).



To test what happens when hours are adjusted because of vintage effects, the high skilled males efficiency age adjusted hours are adjusted for vintage effects. The difficulty in making a vintage adjustment to hours is that hours appear in two places in the quality calculation: In the denominator and in the share weighted logarithmic rates of growth that form the labor input index. In the test, it was determined what the denominator hours would have to be in each year to maintain a constant quality for high skilled males. The efficiency age adjusted hours in each detailed category are then multiplied by the ratio of the constant quality denominator hours to the efficiency age adjusted denominator hours. There are more than 175 of these categories per year with nonzero hours. As Table 3 indicates, the average quality growth rates for the vintage version versus the age only adjustment version are very similar for the period as a whole and for all subperiods except for 2005-2013. After the vintage adjustment, all but two of the last period’s qualities to two digits to the right of the decimal are identical to quality in 1975.

Table 3: Comparison of Quality Growth Rates for High-skilled Males		
	Vintage & Age	**Age Only**
1975-2013	.18	.17
1975-1995	.29	.28
1995-2005	.09	.10
2005-2013	.00	-.03

Conclusion

Hours worked should be age and vintage efficiency adjusted and an index of those adjusted hours with current hours only should be the basis for a production model with TFP. PIAAC enables age adjustments, although clearly it would be preferred to have PIAAC-like information for years before 2012. Vintage adjustments are much more difficult to implement for two reasons. First, how to estimate constant quality as the basis for an efficiency adjustments given that hours appear in two places in quality derived from Törnqvist indexes? Second, although the March CPS Annual Social and Economic Supplement (ASER) is a representative survey, that certainly does not mean that all categories (over 2000 per year in the Christian sample with positive hours) are representative of all individuals in the category. Quality variations over time could be the result of differences in the statistical properties of the sample, rather than indicative of changes in quality. Certainly, the concern with the properties of the ASER sample led both BR and IP to base their featured results on FTFY males. Quality estimation over categories which are representative of their populations is preferred, however, aggregate quality changes over time could be the result of compositional changes rather than changes in the efficiency of hours worked of the underlying representative categories. Categories as detailed as possible are preferred as the assumption that productivity of all individuals in the category is the same is more reasonable. It is likely that both preferences (representativeness and detailed categories) cannot both hold at the same time. The bottom line is that much more research is needed, particularly by individuals knowledgeable about the statistical properties of the ASER sample over time.

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