Efficiency Adjustment of Hours Worked: Two Possible Modifications of a Jorgensen Production Model

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Abstract

This article focuses on two features of the Jorgenson model of production, which is commonly used in productivity research. First, that capital stock is efficiency adjusted in that model, but hours are not. If hours are efficiency adjusted, as proposed in this article, the efficiency per hour of a much younger male college degree worker in a specific year, say 25 years old in 1980, may be different than that of a 50 year old college degree worker in that same year. Second, this article asks whether the assumption of no vitnage effects in the Jorgenson model is valid. In such a model, it is assumed that at the lowest level of detail, the efficiency of a particular type of worker as measured by quality, (marginal product, or labour input divided by hours worked), is constant over time. With no vintage effects, the efficiency of a 50 year old male with a college degree, is the same in 1980 and 2000. Hours are adjusted for efficiency by age using OECD's 2012 Programme for the International Assessment of Adult Competencies (PIAAC).

Estimating total factor productivity (TFP) growth is a challenge. Inputs and outputs have to be quantified over time when demographics and the nature of production processes change, leading to measurement challenges compounded by vintage effects.

In the time period considered,[2] 1975-2013, in the United States, women entered the labour force in significantly larger numbers. In addition, both men and women became more highly educated, with the increase in education levels of women clearly greater than that of men. The age and

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2 The dataset used in the article ends in 2013 and have not yet been updated. However, this has no impact on the major points made in the article.

education composition of the labour force shifted and technology impacted how production took place.

This article proposes adjusting hours worked by workers' efficiency to make it more consistent with physical capital stock and questions the assumption that the quality of an input at the most detailed level is constant over time. The Jorgenson model of production, which is frequently used in productivity research, is the basis for the analysis, a model which was adopted by the U.S. Bureau of Labor Statistics (BLS) with a minor modification.[3]

Adjusting hours worked by workers' efficiency will change the quantity of labour input and measured TFP change. Since capital stock's efficiency adjustment is an age adjustment, a labour input efficiency adjustment follows this adjustment concept. The age hours' efficiency adjustment is based on the age of workers using survey results from the Programme for the International Assessment of Adult Competencies (PIAAC). [4] No attempt is made to determine whether the PIAAC results are a true indicator of the level of efficiency or skills which impact directly on job performance. The purpose of this article is simply to argue for an hours adjustment, not to determine whether PIAAC is the optimal indicator.

One premise of the Jorgenson model of production is that quality of a factor of production at the most detailed level of data available is constant over time. To use an example from Bowlus and Robinson (2012: 4), this assumption means that the "physics task" performed by a 50 year old with a Ph.D. in physics granted to someone from the 1966 cohort compared to someone from a 1946 cohort is the same. Bowlus and Robinson say this is not true not mainly because of the quality of teaching, rather due to the quality of the Ph.D. recipient due to the advanced physics information passed on to the student in the later cohort. The challenge is to be able to test Jorgenson's assumption.

The assumption that quality of an input at the most detailed level of data available is constant over time should not be confused with an assumption that the quality of a factor of production is constant when more than one type of input is included. When more than one type of input is included, BLS calls this composition rather than quality. An input index can reflect changes in the composition of inputs, such as in an index of males and females of a particular type, as well as changes in the quality of an input at the most detailed level of data available. For example, with reference to the composition component, over time as more women are employed, the quality of an input including both males and females typically changes. However, it is not possible to identify within quality change the part that comes from possible changes in

3 The U.S. Bureau of Labor Statistics (BLS) averages the revaluation term in the nominal cost of capital services expression over several years because of this term's impact on nominal capital services. Bowlus and Robinson (2012: 22) note that their results are almost the same whether they use the Jorgenson or the BLS model of production.

4 See the OECD (undated) in the references for the PIAAC literacy, numeracy and problem solving documents.

the quality of an input at the most detailed level over time (the Ph.D. example) and the part that comes from changes in the composition of the input at a higher level of detail when the index includes more than one type of input.

This article contains six sections. The first part provides a description of the Jorgenson production model. The second section describes the Program for International Assessment of Adult Competencies (PIAAC). The third part discusses the adjustment of hours worked by age using PIAAC. The fourth section provides estimates of the impact of PIAAC-adjusted hours adjustment on the contribution of labour and total factor productivity to output growth. The fifth section discusses the existence of vintage effects for workers, that is whether it is possible to determine if the quality of labour at the most detailed level of disaggregation is constant over time. The sixth section concludes.

Jorgenson Production Model

The Jorgenson production model is frequently used to estimate production and the rate of change of TFP.[5]

The most frequently cited source for a description of the Jorgenson production model is Jorgenson, Gollop, and Fraumeni (1987). In the production model, capital and labour differ in that capital input is constructed with physical capital stocks and labour input is constructed with hours worked, a flow. In addition, capital compensation is estimated indirectly with a user cost of capital, or capital service flow, methodology, while labour compensation comes directly from wages paid for hours worked. The nominal dollar accounting identity, the sum of all nominal dollar physical capital and labour compensation, is:

$$\sum P_v V = \sum P_{Kk} K_k + \sum P_{Ll} L_l \qquad (1)$$

where P is price, V is the quantity of value added, K is the quantity of physical capital input with types k, and L is the quantity of labour input with types l. The quantity of value added is determined by a Törnqvist index of the quantity of physical capital input, labour input, and time.

The index of TFP change, $\bar{v}_T$, is a residual

$$\begin{aligned} \bar{v}_T &= \ln V(T) - \ln V(T-1) \\ &= \bar{v}_k[\ln K(T) - \ln K(T-1)] \\ &\quad - \bar{v}_L[\ln L(T) - \ln L(T-1)] \end{aligned} \qquad (2)$$

with

$$\begin{aligned} \bar{v}_K &= \frac{1}{2}[v_K(T) + v_K(T-1)], \\ \bar{v}_L &= \frac{1}{2}[v_L(T) + v_L(T-1)], \\ \bar{v}_T &= \frac{1}{2}[v_T(T) + v_T(T-1)]. \end{aligned} \qquad (3)$$

5 The Jorgenson production model is often called KLEMS (physical capital, labour, energy, materials, and services).

$$v_K = \frac{P_K K}{\sum P_V V}, \qquad v_L = \frac{P_L L}{\sum P_V V}. \tag{4}$$

The terms $\overline{v}_K[\ln K(T) - \ln K(T-1)]$ and $\overline{v}_L[\ln L(T) - \ln L(T-1)]$ are frequently called respectively the contribution of physical capital and labour input to economic growth. The quantity of physical capital and labour input are computed using a Törnqvist index.[6]

$$\begin{aligned} \ln K(T) - \ln(K(T-1)) = \\ \sum \overline{v}_{Kk}[\ln K_k(T) - \ln K_k(T-1)], \\ \ln L(T) - \ln(L(T-1)) = \\ \sum \overline{v}_{Ll}[\ln L_l(T) - \ln L_l(T-1)], \end{aligned} \tag{5}$$

where

$$\begin{aligned} \overline{v}_{Kk} &= \frac{1}{2}[v_{Kk}(T) + v_{Kk}(T-1)], \\ \overline{v}_{Ll} &= \frac{1}{2}[v_{Ll}(T) + v_{Ll}(T-1)], \\ v_{Kk} &= p_{Kk}K / \sum p_K K, \\ v_{Ll} &= p_{Ll}L / \sum p_L L. \end{aligned} \tag{6}$$

In all of the Törnqvist input indexes, once the growth rates are determined, typically the base year is set to nominal dollar physical capital input (also called capital services) or nominal labour input, then the growth rates are applied to generate a sequence of quantity estimates. As previously noted, physical capital input is derived from physical capital stock. The flow of the quantity of capital input, is assumed to be proportional to the quantity of physical capital stock, $A_k(T-1)$ Jorgenson, Gollop, and Fraumeni (1987:13):

$$K_k(T) = Q_{Kk} \cdot A_k(T-1), \tag{7}$$

where the constants of proportionality or quality variables, Q_{Kk}, transform physical capital stock to the flow of capital services. The flow of the quantity of labour input is assumed to be proportional to hours worked, $H(T)$. The constants of proportionality or quality variables, Q_{Ll}, transform hours worked to the flow of the quantity of labour input.

$$L_l(T) = Q_{Ll} \cdot H(T). \tag{8}$$

It is important to note that in equations 7 and 8, the quality or constants of proportionality variables, Q_s, do not depend on time, T. This feature of the Jorgenson production model is equivalent to assuming that no Jorgenson-defined vintage effects occur.

In practice, quality for both physical capital and labour input is determined by dividing the Törnqvist quantity of physical capital or labour input by lagged physical capital stock or hours worked, respectively. Hours worked is an unweighted summation, but the quantity of physical capital stock, A_k, is a weighted summation. Using the

6 In a Törnqvist index, the nominal dollar shares reflect the relative marginal products (and wages of or rate of return to) inputs.

perpetual inventory method, $(1-\delta_k)$ are the weights applied to the previous year's physical capital stock, with δ_k as the geometric depreciation rate.

$$A_k(T) = I_k(T) + (1-\delta_k) \cdot A_k(T-1), \quad (9)$$

where $I_k(T)$ is the quantity of physical capital investment.

The depreciation rate is an efficiency adjustment as it reduces the contribution of past investments to physical capital inputs based on the age of the physical capital stocks.

To summarize, there are two differences in the Jorgenson production model between physical capital and labour:

1) Physical capital stocks are efficiency adjusted, but hours worked are not, and

2) The quantity of physical capital input depends on a stock measure while the quantity of labour input depends on a flow measure. [7]

To allow for efficiency adjustment of hours for consistent treatment of labour and capital and the possibility that neither quality of capital or labour is constant at the lowest level of detail, the following two new equations could be added to the model of production:

$$K_k(T) = Q_{Kk}(T) \cdot A_k(T-1), \quad (10)$$

$$L_l(T) = Q_{Ll}(T) \cdot (1-\delta_h) \cdot H(T), \quad (11)$$

where $(1-\delta_h) \cdot H(T)$ is efficiency adjusted hours and $(1-\delta_h)$ is the hours adjustment factor which could vary by the age or some other characteristic of workers.

Program for the International Assessment of Adults Competencies (PIAAC)

The OECD sponsors the Program for the International Assessment of Adults Competencies (PIAAC), a survey of adult competencies, conducted in the first cycle between 2011 and 2018 in 39 countries including the United States (OECD, undated, Survey of Adult Skills (PIAAC)). The PIAAC survey measures the key cognitive and workplace skills which are thought to be needed for individuals to participate in society and for economies to prosper. Five thousand individuals per country between the age of 16 and 65 are interviewed in their home as part of the survey. In 2012, the skills measured are literacy, numeracy, and problem solving in technology-rich environments.[8]

On the PIAAC design web site, three sample questions are given for each of the skills, accessible from the web site that lists the skill definitions. The PIAAC web site states "Literacy is the ability to understand and use information from written texts in a variety of contexts to achieve

7 The stock versus flow issue is not going to be explored in this article. This stock versus flow issue could become a problem when econometric models determine the rate of change in TFP on the basis of output and hours, which are both flows, and physical capital stocks, without being aware of underlying assumptions needed to do so such as those in the Jorgenson model of production.

8 The three skill definitions are found at https://www.oecd.org/skills/piaac/.

goals and develop knowledge and potential."[9] "Numeracy is the ability to use, apply, interpret, and communicate mathematical information and ideas."[10] Referring to problem solving in technology-rich environments, the PIAAC web site states, "This refers to the ability to use technology to solve problems and accomplish complex tasks. It is not a measurement of "computer literacy", but rather of the cognitive skills required in the information age – an age in which the accessibility of boundless information has made it essential for people to be able to decide what information they need, to evaluate it critically, and to use it to solve problems.'[11]

There are two alternative sets of PIACC results, one by gender and one by qualifications. These will not be explored in this article.

Adjustment of Hours Worked by Age Using PIAAC in the United States

Hours worked are now going to be efficiency adjusted to remove the inconsistency between physical capital and hours worked. As previously noted, hours worked in a Jorgenson production model are an unweighted summation of hours worked without any efficiency adjustment, whereas the quantity of capital stock is efficiency adjusted.

PIAAC results support the notion that the efficiency of hours worked by individuals vary by age in the United States. As a starting point is this article's proposal to efficiency adjust both physical capital stocks and hours worked, the efficiency of hours worked will be allowed to vary by age based on the PIAAC survey results as the efficiency of physical capital stocks vary by age in the Jorgenson production model. In contrast to physical stocks which decline in efficiency as assets age, hours worked are allowed to increase in efficiency as younger workers age, before hours worked efficiency are allowed to decline in efficiency, at least through age group 55 and over.

Table 1 shows the PIAAC results[12] and the adjustments to hours worked equal to

9 Three sample questions start with a list of nine preschool rules. The test taker is first asked by what time children should arrive at preschool. The second and third depend on reading a chart of 13 types of physical exercise equipment classified by nine different effects. The first question using this chart asks the test taker to determine which muscles will benefit the most if you use a gym bench. The second question using this chart asks the test taker to determine which equipment listed has the most ineffective ratings.

10 The test taker is asked what the Celsius temperature would be if the temperature decreases by 30 degrees. Next, a brief set of information is given about a closed nuclear reactor and wind power stations in Sweden. The question asks the test taker to determine how many wind power stations would be needed to replace the power generated by the closed nuclear reactor. The last question relies on a graph showing births for every 10 years in the United States from 1957 to 2007. The question asks the test taker to indicate the period(s) for which there was a decline in births.

11 All three questions depend on use of websites. The test taker is asked to find which job search web sites of those shown, with live links, do not charge a fee and do not require that you register. The object is to bookmark these websites, but not until you have determined that they meet the requirements. Investigation requires one to link to connected websites to learn more before making a decision.

12 All PIAAC data and information in this article were obtained through the data base accessing site found at https://piaacdataexplorer.oecd.org/ide/idepiaac/.

13 There are three possible sources of PIAAC hours worked age adjustments. The results in this article feature that from 2012, but there is also a combined 2012/14 sample and the 2017 PIAAC. 2012 is featured in this

Table 1: PIAAC Results by Age and Hours Worked Efficiency Age Adjustment Based on 2012 PIAAC*

Skill	Age Groups 16-24**	25-34	35-44	45-54	55 & over
Literacy***	272 (2.0)	275 (2.0)	273 (1.8)	266 (1.7)	263 (1.5)
Numeracy***	249 (2.2)	260 (2.2)	258 (1.9)	250 (2.1)	247 (1.8)
Problem Solving in Technology- Rich Environments***	285 (2.2)	283 (2.0)	279 (2.2)	271 (1.7)	267 (2.5)
Average Score	269	273	270	262	259
Hours Efficiency Adjustment***	.985	1.000	.990	.962	.950

*Standard errors are listed in parentheses.
**The hours worked efficiency adjustment listed in this column is applied to those aged 15-24.
***No significant differences in averages for Literacy (24 or less vs. 25-34, 24 or less vs. 35-44, 45-54 vs 55 & over); Numeracy (24 or less vs 45-54, 24 or less vs 55 & over, 25-34 vs 35-44, 45-54 vs 55 & over); Problem Solving (24 & less vs 25-34, 25-34 vs 35-44, 45-54 vs 55 & over)
Source: OECD

(1 - δ_h) that are applied in all years to all workers based on the 2012 PIAAC. [13] Note that the problem solving skill is the only one that monotonically declines by age group. In addition, across all skills, the largest falloff in scores between two age groups is between the 35-44 and 45-54 age groups (0.038). Because efficiency is set to 1.0 in the age group (25-34) with the highest average skill score, adjusted hours worked are lower than unadjusted hours worked for all other age groups. The 55 and over age group has an efficiency level 0.950 of that of the 25-34 age group, while the corresponding ratio for 45-54 age group was 0.962 per cent , 0.990 per cent for the 34-44 age group, and 0.985 per cent for the 16-24 age group.

Chart 1 shows the average percentage difference between unadjusted and adjusted hours between 1975 and 2013 where the Christian database is the source for hours (Christian, 2016).[14] The reduction drops from 2.06 per cent in 1975, to the smallest reduction of 1.75 per cent in 1987, before increasing to 2.41 per cent in 2013.[15] This reduction is driven by the change in the age distribution of the working age population. 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 (Colby and Ortman, 2014:2). Over the 1975 to 2013 period, there were notable changes in the shares

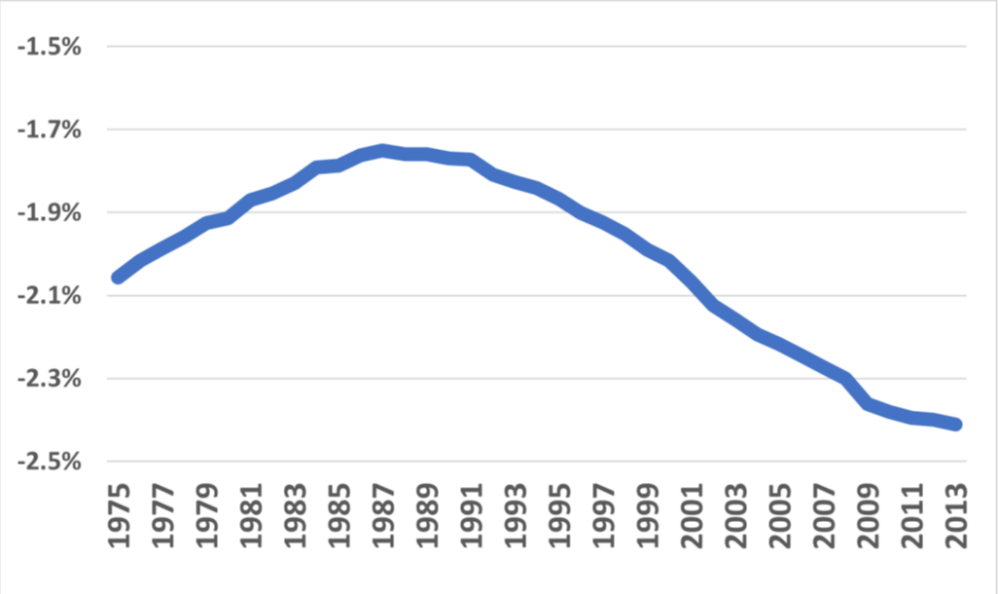
article rather than the two other possibilities for three reasons: 2017 is beyond the period covered in this article, 2012 is closer to the earlier years in the analysis than the combined 2012/14 sample, and the statistical properties, such as standard errors and P-values, could not be found online for the combined 2012/14 sample when this estimates in this article were constructed. The hours reduction is greatest in the 2012/14 sample and the smallest in 2012.

14 Christian hours are not efficiency adjusted.

15 It does not matter whether the PIAAC ratings are scaled with the lowest or the highest PIAAC rating being set to one as the logarithmic rate of change in hours from year to year would remain the same. In a Törnqvist index it is the logarithmic rate of change that matters, not the number of hours worked.

16 See Gobbi and Chabé-Ferret (2019) for a discussion of birth rates by generations. OECD, (2019: Chart 9)

Chart 1: Reduction in Hours Worked with the Age Efficiency Adjustment Based on PIAAC in the United States, 1975, 1987 and 2013 (Per cent of total)



Source: Author's compilations.

of hours worked by age categories (Chart 2).[16]

The PIAAC skill measures imperfectly capture how skills impact work performance. For example, if an individual performs unskilled labour, how important are the three skills?[17] However, the use of PIAAC skill indicators are useful as they demonstrate the concept of efficiency adjustment for hours worked.

There are other possible factors that could be used to determine worker efficiency by age. Paullin (2014) has listed a number of these as they impact on what she calls "mature" workers (Exhibit 1). Although she notes that mature workers are thought to be those generally above age 50 or 55, she also notes that age is not the only indicator of maturity.[18] There are no numerical indicators of the impact on younger and mature workers in her analysis.

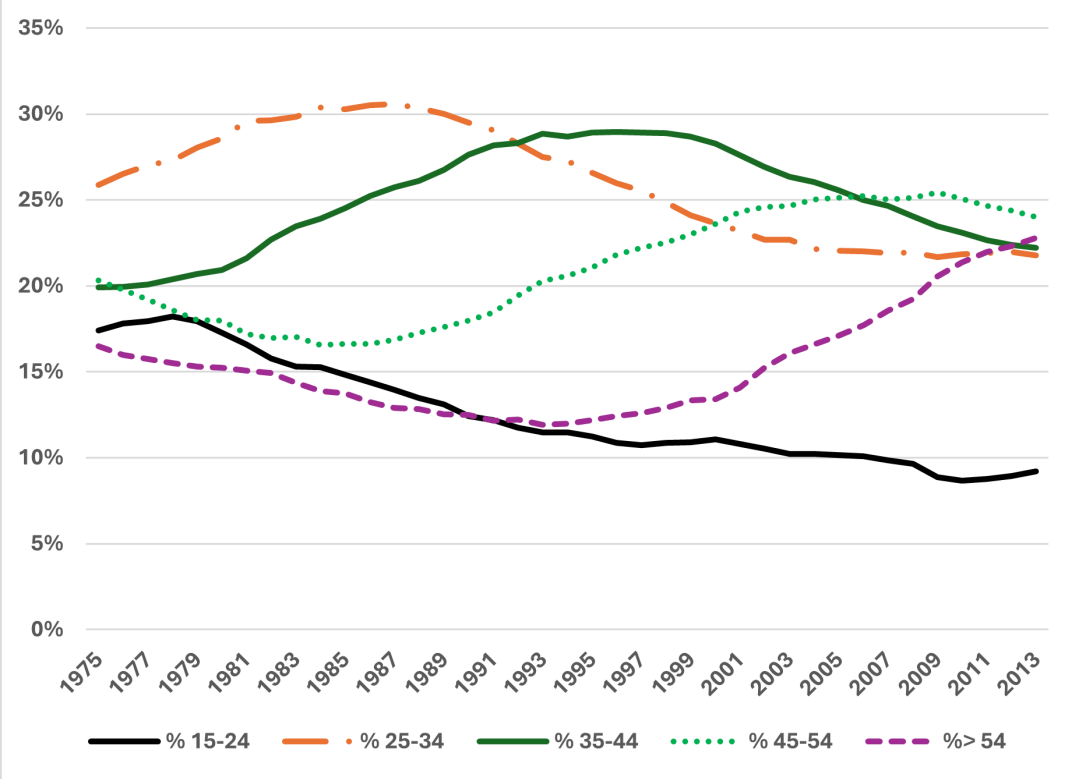
Impact of PIAAC-based hours adjustments on the contribu-

shows literacy and numeracy scores of individuals by a representative sample of age groups who participated in the Programme for the International Assessment of Adult Competencies (PIAAC) both in 2012/2014 and in 2017. This chart shows that differences occurred as individuals aged with results from participants in the 2012/14 and 2017 U.S. surveys.

17 My personal example regarding the importance of numeracy (or at least basic mathematics knowledge) for a worker performing unskilled labour is the following from a number of years ago. At my former house, a thick, large stone, New England wall was being constructed. A sub-contractor quoted the price based on surface area (length times height), instead of by cubic feet (length times height times width). The wall builder was very upset at the amount he was paid for the completed wall, but the low payment was due to the fact that the sub-contractor did not take into account the width of the wall in his quotation.

18 Paullin (2014:2) cautions that "No matter which number is chosen, chronological age is not the best way to define the mature worker. People vary in terms of when and how they experience aging and whether they perceive themselves as aging. Factors that should be taken into account in addition to chronological age include physical, mental and emotional health; career stage; job tenure; and life experiences."

Chart 2: Share of Total Hours Worked by Age Group in the United States, 1975-2013



Source: Author's compilations.

Exhibit 1: Relationship Between Job Performance and Age

Factor	Relationship
Core task performance	No consistent relationship up to mid-60s
Performance quantity	May be higher for younger workers
Performance quality	May be higher for mature workers
Organizational citizenship behaviors	Higher for mature workers
Counterproductive work behaviors	Lower for mature workers
Self-reported health problems	Similar levels through middle age, then higher levels with advancing age
Clinical indicators of health	Worse for mature workers
Resistance to change	May be lower for mature workers
Innovative behaviors	No relationship
Organizational commitment	Higher for mature workers
Turnover intentions	Lower for mature workers

Source: Paullin (2014)

tion of labour and TFP to output growth

Changes in the rates of growth of contributions of labour input to growth in output are small with a PIAAC-based hours adjustment. This means the changes in the rates of growth of TFP, which is a residual (see equation 2), are also small. Using unadjusted (base case) and adjusted hours from the Christian database (Christian, 2016) and the average nominal share of labour compensation in nominal value added from Fraumeni and Christian (Fraumeni and Christian, 2019), the rates of change of hours and the contributions of labour input are estimated. In a Törnqvist index of labour input, the quantity of labour input is determined from the logarithmic rate of growth of hours weighted by the average nominal labour compensation share. Accordingly, the contribution of labour input to economic growth varies if the average labour compensation share or the rate of growth of hours changes.

The focus is on the logarithmic rate of change in hours with or without PIAAC based adjustment as all other components of TFP are the same. The logarithmic growth rates of hours worked by selected time periods decline for the no hours adjustment base case and for the hours age adjustment scenario (Table 2). If a logarithmic rate of change in hours increases in the PIAAC age adjustment case compared to the no hours adjustment base case, the rate of change of TFP decreases compared to the base case; if it decreases, the rate of change of TFP increases. Table 2, for the base case and for the hours adjustment scenario, shows all components of the rate of contributions of labour input to economic growth, for the adjusted hours labour contribution, and adjusted hours labour contribution less the base case. If the difference is positive, the rate of change of TFP is lower as a greater portion of economic growth is measured as coming from labour input; if it is negative the rate of change of TFP is higher. The results show that for the age efficiency adjustment reduced the labour input by 0.01 percentage points per year, and thereby increased TFP growth by the same amount. This is a very small effect.

Quality Constancy at the Most Vintage Detailed Level of Data Available

As previously noted earlier in the article, the Jorgenson production model assumes that the quality of inputs is constant over time at the lowest level of detail available in the data (equations 7 and 8). If the quality of labour input changes at this lowest level of detail over time, the Jorgenson model assumption is violated.

Inklaar and Papakonstantinou (2020) followed the methodology of Bowlus and Robinson (2012) to estimate vintage effects of the United States versus six European countries to determine if the Jorgenson assumption is violated and to determine the size of the vintage effect. Inklaar and Papakonstantinou find that Bowlus and Robinson defined vintage effects can occur for several reasons: The quality of students, the quality of higher education (the Ph.D. in physics example), and changes in workers' human capital production func-

Table 2: Effect of Efficiency Adjustment of Hours on Labour Input

	Average Nominal Labour Share	Logarithmic Hours Rates of Growth		Contributions of Labour Input (pp.)		Difference between Base and Adjusted Hours Contributions
Year		Base	Age Efficiency Adjusted	Base	Age Efficiency Adjusted	(Adjusted–Base)
1976–1985	0.566	0.0225	0.0228	0.0127	0.0128	0.0002
1986–1995	0.574	0.0168	0.0167	0.0096	0.0096	0.0000
1996–2005	0.576	0.0142	0.0138	0.0080	0.0078	-0.0002
2006–2013	0.551	0.0012	0.0009	0.0006	0.0005	-0.0001
1976–2013	0.568	0.0143	0.0142	0.0081	0.0080	-0.0001

Author's calculations based on OECD, PIAAC estimates for 2012 (Table 1) and hours worked constructed by Christian (Fraumeni and Christian, 2019; Christian, 2016).

tion. They note that it is possible that when more students attend higher education, the average quality of graduates given a constant quality of higher education may decline. Inklaar and Papakonstantinou 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.

Inklaar and Papakonstantinou conclude that Bowlus and Robinson defined vintage effects, are important in the United States looking at full-time-full-year (FTFY) non-self-employed males. Their estimates for high-skilled male workers in this category indicated that labour services per hour (quality) increased by 25 per cent between 1975 and 2015, with most of the increase (19 per cent) occurring between 1995 and 2005. For the same FTFY male category of workers, but having medium skills, labour services per hour decreased 10 per cent, 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, labour services per hour decreased substantially during 1975-1995, with a total decline of 20 per cent for the whole period (Inklaar and Papakonstantinou, 2020:11-12).

Changes in deflated median wages over time is also an indication of Bowlus and Robinson defined vintage effects according to Inklaar and Papakonstantinou. By age groups, for U.S. high-skilled workers deflated median wages over the period 1995-2005, median wages of young workers aged 26-35 increased by 6.2 per cent, median wages of middle-aged workers aged 36-49 increased by 12.6 per cent, and median wages of old workers aged 50-59 decreased by 1.2 per cent (Inklaar and Papakonstantinou, 2020:18, Table 9).

There are two reasons to question the validity of Inklaar and Papakonstantinou's results challenging the Jorgenson model of production constancy assumption, even though it is likely that the constancy assumption is violated in at least some cases. First, the results in their paper are for labour input potentially having distinctly different characteristics within this category, e.g. FTFY non-self-employed high-skilled males.[19] Certainly in such a broad category there are composition ef-

19 High-skilled males are defined as those who have a bachelor's degree or above.

fects which can mask the extent to which the constancy assumption is violated at a more detailed level of labour input.[20] Their results are not for the individual who has a Ph.D. in physics.

Second, and most importantly, the nominal wage rates per hour worked are deflated by a U.S. consumer price index (CPI). When the CPI goes up or down, is it true that the average marginal productivity of workers has changed? If the U.S. economy was perfectly competitive, wages should instantaneously, or very quicky, adjust to inflation for those whose marginal productivity has not changed. Clearly, this is not the typical case although wages frequently adjust over time. The lack of detail on worker's characteristics, such as occupation, and a CPI to deflate nominal wages per hour worked means that Inklaar and Papakonstantinou's estimates of the extent to which quality is not constant at the detailed level cannot be accepted as valid estimates.

Conclusion

This article demonstrates that it is possible to efficiency adjust hours worked, but not possible to estimate to what extent the Jorgenson model lowest level of data detail available quality constancy assumption is violated using the approach of Inklaar and Papakonstantinou.

Efficiency adjusting hours will result in at least somewhat different measures of labour input and TFP. The impact of an hours efficiency adjustment shown in Table 2 is at most ± 0.02 percentage points. This is quite small, but other adjustment factors might result in a greater effect. Arguments advanced by both Bowlus and Robinson and Inklaar and Papakonstantinou suggest that the quality constancy is probably violated in at least some cases, but the Inklaar and Papakonstantinou estimates are not valid estimates of the size of the violation because of the highly aggregated data and the choice of a CPI as a nominal wage deflator.

Hopefully, future research will be done to develop more sophisticated hours efficiency adjustments which relate directly to skills used on the job and to produce another set of estimates of the size of possible violations of the constancy assumption.

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