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VINTAGE EFFECTS IN HUMAN CAPITAL: EUROPE VERSUS THE UNITED STATES

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The standard assumption in growth accounting is that an hour worked by a worker of given type delivers a constant quantity of labor services over time. This assumption may be violated due to vintage effects, which were shown to be important in the United States since the early 1980s, leading to an underestimation of the growth of labor input (Bowlus and Robinson, 2012). We apply their method for identifying vintage effects to a comparison between the United States and six European countries. We find that vintage effects led to increases of labor services per hour worked by high-skilled workers in the United States and United Kingdom and decreases in Continental European countries between 1995 and 2005. Rather than a productivity growth advantage of the US and UK, the primary difference with Continental European countries was human capital vintage effects instead.

JEL Codes: O11, J31, E24

Keywords: human capital, productivity, vintage effects

1. Introduction

Improvements in human capital have long been thought to contribute only modestly to economic growth, following the growth accounting method of Jorgenson and Griliches (1967).[1] For example, Jorgenson et al. (2016, Table 4) show that the United States economy grew at an average annual rate of 3.23 percent between 1947 and 2010 and that human capital improvements only contributed 0.24 percentage points to this total, with little variation in this contribution over time.[2] Growth accounting relies on the assumption that an hour worked by a person of given type—distinguished by education, age and gender—provides a *constant quantity of labor services* over time. Yet this assumption is increasingly challenged on both theoretical and empirical grounds as the quality of education and post-education accumulation of human capital may change over time; see

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[1]See Hulten (2010) for a more recent survey.

[2]Jones (2016, p. 11) shows very similar estimates.

Lucas (2015). Bowlus and Robinson (2012) contribute to this literature by modifying the growth accounting method to accommodate vintage effects, whereby new graduates may differ from previous cohorts in terms of the quantity of labor services per hour worked that they supply, for instance due to improved schooling or on-the-job training.[3] Applying their method to data for the United States between 1963 and 2008, they find that the quantity of labor services per hour worked by college-educated workers increased substantially. As a consequence, they argue that there is a larger role for human capital in accounting for US growth than based on the traditional 'constant quantity' assumption.

An important question is whether the Bowlus and Robinson (2012) results can be generalized to a broader set of countries. A comparison with European countries is especially interesting as productivity growth in the US accelerated in the mid-1990s, while European productivity lagged behind. Standard growth accounting shows no important role for differences in human capital improvements in accounting for these differences (Timmer et al., 2013), but if vintage effects led to higher growth of (effective) labor input in the US but not in Europe, that could provide a more focused target for analysis and economic policy. To address this question, we apply the Bowlus and Robinson (2012) method to a more recent period for the US, covering the 1975–2014 period (using data from the Current Population Survey, CPS) and to six European countries – France, Germany, Italy, the Netherlands, Spain and the United Kingdom—covering the period from the mid-1990s to 2013 (with coverage varying by country) using the Luxembourg Income Study (LIS) database.

In standard growth accounting, the quantity of labor services provided by a given type of worker is assumed to be constant over time. Observing an increase in workers' wages then implies that the price of that type of human capital—the price per unit of labor services—has increased. The novelty of the Bowlus and Robinson (2012) method is that it drops the assumption that an hour worked by a worker of a given skill level delivers a constant amount of labor services over time and thus that increases in wages are increases in the price of human capital. The method does so by drawing on the literature on life-cycle earnings (Ben-Porath, 1967) and earlier work by Heckman et al. (1998). The key assumption of Bowlus and Robinson (2012) is that changes in the price of human capital (at a particular educational level) can be identified only for workers at a late stage in their life cycle, at a point where these older workers no longer increase their productivity. Put differently, there is a period in a worker's life cycle during which worker productivity is constant, a so-called flat spot range.

This point is illustrated in Figure 1, which shows a smoothed curve of (the log of) the median hourly wage of high-skilled workers in the US in 1995 and 2005. We draw two important observations from this figure. First, wages increase rapidly with age, but after the age of 50 there is no clear trend. This observation, analyzed more extensively in Bowlus and Robinson (2012), is at the heart of the empirical argument for a flat spot range in human capital accumulation: after a certain age, a typical worker's wage no longer increases, indicating their human capital no longer increases. The second observation is that the age-wage profile can change its shape over time: the 2005 profile is higher than the 1995 at all points, but substantially

[3]We use the term "vintage effects" throughout, but the literature also refers to these as "cohort effects".

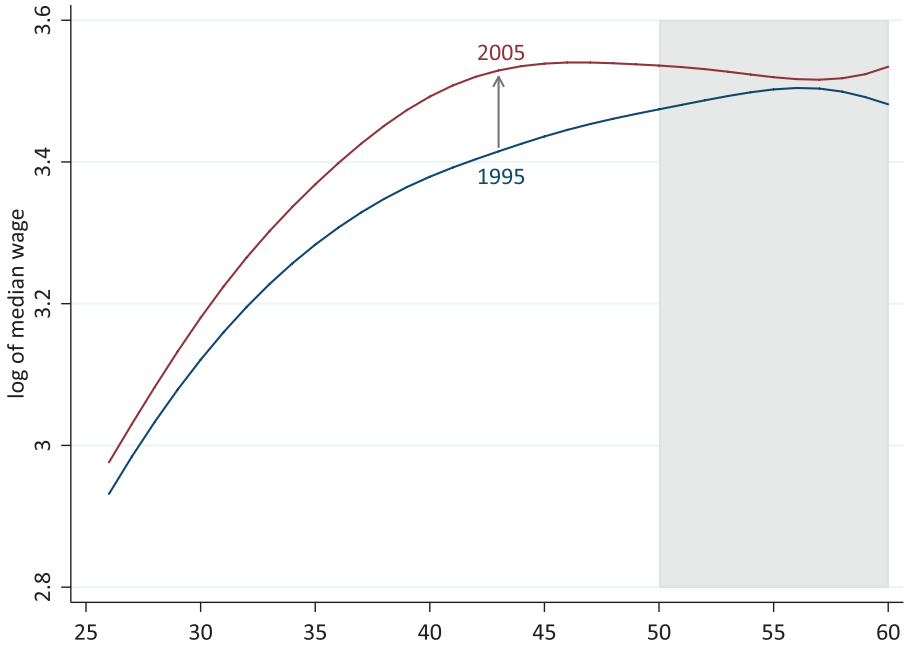

Figure 1. Age-Wage Profile for High-Skilled Workers in the United States, 1995 and 2005.

Source: Calculations based on the Current Population Survey from IPUMS-CPS (Flood et al., 2015).

Notes: The figure shows the results for a LOWESS smoother with bandwidth parameter 0.8 over the median wage at each age for full-time, full-year male employees with a bachelor's degree or above. Wages are deflated using the consumer price index. [Colour figure can be viewed at wileyonlinelibrary.com]

so in the middle of the age distribution and only modestly so after the age of 50. These ingredients of the Bowlus and Robinson (2012) method are used to establish that this group of workers has increased its human capital, i.e. increased the quantity of labor services per hour worked. In contrast, in standard growth accounting, changes in the quantity of labor services per hour worked for a particular type of worker are ruled out and this type of wage increases is assumed to reflect a higher price for labor services supplied by high-skilled workers in that age range.

The main finding in Bowlus and Robinson (2012) is that, starting around 1980, wages of high-skilled workers in the US increased relative to the price of high-skilled labor (i.e. the wages of workers in the flat-spot range), while the wages of medium-skilled and (especially) low-skilled workers declined relative to the price of each labor type.[4] So labor services per hour worked by high-skilled workers increased, while labor services per hour worked by medium- and low-skilled workers declined. Combined with the increased share hours worked by of high-skilled, this implies that standard growth accounting substantially underestimates the contribution of improvements in human capital to US growth and overestimates the role of (multifactor)

[4]High-skilled workers have completed tertiary education (ISCED levels 5 or 6), medium-skilled workers have completed secondary education (ISCED levels 3 or 4), and low-skilled workers have not completed secondary education (ISCED levels 0, 1 or 2).

productivity growth, which is determined as a residual. An alternative perspective would be that the US saw more embodied and less disembodied technical change. Indeed the Bowlus and Robinson (2012) results indicate that uncounted human capital improvements may have been large enough to eliminate productivity growth entirely.

The (simplified) illustration of the Bowlus and Robinson (2012) method in Figure 1 points to a limitation of the method: while the method identifies changes in the quantity of labor services per hour worked, it does not provide direct evidence on the underlying causes.[5] In general, though, based on human capital theory, we can distinguish a set of possibilities. The following examples focus on high-skilled (i.e. university-educated) people for expositional ease and because our results show most changes in this category. A first explanation could be selection effects: if a larger share of a cohort of pupils enters higher education, this could decrease the average ability level and thus lead to lower labor services per hour worked for that cohort of university graduates. Alternatively, if the quality of higher education improves later cohorts may leave university with higher levels of human capital, allowing these cohorts to provide more labor services per hour worked. More, or more effective on-the-job training can also improve labor services per hour worked of later cohorts. And finally, technological factors may play a role. For example, the increased role of information and communication technologies (ICT) could particularly benefit high-skilled workers, given the well-established complementarity between ICT and high-skilled workers (e.g. Michaels et al., 2012). Furthermore, this complementarity may be stronger for younger cohorts, who are still investing in new skills.

In our analysis, we find that vintage effects continue to be important in the United States in recent years. Between 1975 and 2014, labor services per hour worked of high-skilled workers have increased by 25 percent when applying the Bowlus and Robinson (2012) method. By contrast, labor services per hour worked of medium-skilled workers have declined by 9 percent and those of low-skilled workers have declined by 20 percent. The declines for medium- and low-skilled workers were concentrated in the first half of the period, until 1995. The increase for high-skilled workers was concentrated in the period 1995–2005, which coincides with the period during which US labor productivity growth was (temporarily) higher fueled (in part) by rapid ICT investment.[6]

Within Europe, the UK's experience is most similar to that of the US, with increases of labor services per hour worked by high-skilled workers between 1995 and 2005. The Continental European countries – France, Germany, Italy and the Netherlands—instead show declines of 10 to 14 percent in labor services per hour worked by high-skilled workers over this same period. The differences between the Anglo-Saxon and Continental European countries remain throughout the sensitivity analyses that change key assumptions or modify the treatment of the basic data.

These differences suggest that human capital vintage effects were an important factor in accounting for the productivity growth difference between Europe

[5]See also Lagakos et al. (2018) on the difficulties of empirically distinguishing different theories to explain differences in labor services per hour worked.

[6]See e.g. Byrne et al. (2016) on the timing of US productivity growth episodes.

and the United States between 1995 and 2005, the topic of a sizeable literature.[7] Under standard growth accounting methods, the US and UK had a productivity growth advantage over the Continental European countries in our analysis—France, Germany, Italy, Netherlands, and Spain. Accounting for the increases in the quantity of labor services per hour worked in the UK and US and the decreases in the Continental European countries eliminates most of the differences. Only Italy and Spain remain exceptional, with declining productivity over this period. Recent research on this topic has emphasized a deterioration in the capital allocation process in Italy and Spain, suggesting theirs was the exceptional productivity growth experience rather than the UK or US.[8]

As discussed above, the method of Bowlus and Robinson (2012) does not clarify the source of the vintage effects—and thus also not why the US and UK show increases in labor services per hour worked by high-skilled workers, while the Continental European countries show declines between 1995 and 2005. That said, the timing of these differences in combination with the broader literature suggests that an explanation which fits the observed difference in vintage effects is one that centers on the much stronger ICT investment boom in the US and UK starting in the mid-1990s.

In measuring vintage effects for human capital, this paper adds to a recent, growing literature on this topic. Lagakos et al. (2018) show that experience-earnings profiles are much steeper in high-income economies than in lower-income economies. Their analysis is based on a similar approach as that of Bowlus and Robinson (2012) and ours, but applied in a cross-country setting. They conclude that workers in high-income countries—and especially high-skilled workers are able to accumulate human capital more rapidly during their career than workers in low-income countries. In a similar vein, Manuelli and Seshadri (2012) find that workers in high-income countries have "higher quality" human capital, which may also be due to more rapid accumulation of human capital on the job. Further empirical support for systematically higher quality of education in high-income countries is provided by Kaarsen (2014). Hanushek and Woessmann (2012) show that a higher quality of education leads to faster economic growth. These are specific examples of studies in a more general trend to accommodate a large role for human capital in accounting for growth or income level differences; see e.g. Lucas (2015) for a general discussion of this stream of literature and Jones (2014) as another prominent example of how the traditional growth accounting method is likely to understate human capital's importance by emphasizing imperfect substitutability between workers with different skill levels. Fraumeni (2015) provides a more in-depth overview of how different measures of the amount of human capital in a country can lead to very different rankings across countries, emphasizing that measurement choices in this area matter substantially. Finally, O'Mahony (2012) is an example of what can still be achieved within the scope of the growth accounting method by using data about on-the-job training to infer investments in human capital during workers' careers. She also finds that failure to account

[7]See e.g. Ortega-Argilés (2013) for a survey or van Ark et al. (2008) for a notable contribution.
[8]See Cette et al. (2016) and Gopinath et al. (2017).

for these investments understates the contribution of human capital to economic growth.

2. METHODOLOGY

2.1. *The Price of Labor Services*

The methodology used to calculate the price per unit of labor services is based on the work of Bowlus and Robinson (2012). It starts from the premise that the hourly wage of an individual (with a given educational level) of age i in period t $(w_{t,i})$is the product of the price of a unit of labor services in that period (p_t) and the quantity of labor services the individual supplies per hour of work $(q_{t,i})$:

$$w_{t,i} = p_t \times q_{t,i} \tag{1}$$

Between two periods, $t-1$ and t, changes in wages will thus be determined by changes in prices and quantities as:

$$\Delta \log (w_{t,i}) = \Delta \log (p_t) + \Delta \log (q_{t,i}) \tag{2}$$

with Δ as the difference operator. The problem with the above-outlined relationships is that only the hourly wage is observed and the price and quantity of labor services are not, leading to an under-identification problem. To overcome this, Bowlus and Robinson (2012) use the insight of the Ben-Porath (1967) model that the quantity of labor services remains constant at a late stage in a person's working life. When young, people invest in their human capital in the formal education system, while no time is spent on work. As they grow older, they allocate their time to both working and producing further human capital through on-the-job training. With the age of retirement approaching, the incentive to further invest in human capital disappears, so time is now solely spent on work. As a result, the quantity of labor services enters a flat spot range. Without any change in quantity between two periods within this flat spot, one can derive changes in prices directly from changes in wages, i.e. $\Delta \log (w_{t,i}) = \Delta \log (p_t)$. For example, if the flat spot range starts at 51, the price change can be inferred by comparing the hourly wage of 51-year olds in year 1 to the wage of 52-year olds in year 2.

More specifically, let us assume that all individuals of a given age (and education level) in our sample[9] are homogenous, so we can summarize the wage within each age-education cell as the median across all workers in this cell, denoted by $\log(\tilde{w}_{t,i})$ for age i at time t. We rely on the median here (as do Bowlus and Robinson, 2012), because the number of workers in a given age-education cell can be small and using the median rather than the mean avoids undue influence from outliers. Depending on the length of the flat spot range and the frequency of the surveys we have N wage differences in the flat spot range. For example, if the length of the flat

[9]The analysis is limited to male workers that work for the full year and have a full time job; see below for further discussion.

spot range is 10 years and we have annual surveys, $N=9$ because we compared the wage of 51-year olds in year 1 to the wage of 52-year olds in year 2 all the way to comparing the wage of 59-year olds in year 1 to the wage of 60-year olds in year 2. If surveys are several years apart, N will be smaller so denote the number of wage differences in the flat spot range between years t and τ as $N_{t,\tau}$. Given this notation, the price series from $t=0,\ldots,T$ for labor services per hour worked can be computed as:

$$
\begin{aligned}
&t=0 && \log\left(p_0\right)=0\\
&t=1 && \log\left(p_1\right)=\frac{\sum_{i=1}^{N_{1,0}}\left[\log\left(\tilde{w}_{1,i}\right)-\log\left(\tilde{w}_{0,i}\right)\right]}{N_{1,0}}+\log\left(p_0\right)\\
&t=2 && \log\left(p_2\right)=\frac{\sum_{i=1}^{N_{2,1}}\left[\log\left(\tilde{w}_{2,i}\right)-\log\left(\tilde{w}_{1,i}\right)\right]}{N_{2,1}}+\log\left(p_1\right)\\
&\vdots\\
&t=T && \log\left(p_T\right)=\frac{\sum_{i=1}^{N_{T,T-1}}\left[\log\left(\tilde{w}_{T,i}\right)-\log\left(\tilde{w}_{T-1,i}\right)\right]}{N_{T,T-1}}+\log\left(p_{T-1}\right)
\end{aligned}
\tag{3}
$$

As discussed below, the length of the flat spot range is set to ten years. For example, for those who have completed tertiary education in the US, it lies between the ages of 50 and 59. This results in a total of nine wage differences (each denoted as $\log(\tilde{w}_{2,i})-\log(\tilde{w}_{1,i})$, for example between years 1 and 2) when data for adjacent years are available. We average across these wage differences (in equation (3) this would be denoted as $\sum_{i=1}^{N_{2,1}}\left[\log\left(\tilde{w}_{2,i}\right)-\log\left(\tilde{w}_{1,i}\right)\right]/9$) to derive the price per unit of labor services.

We estimate prices per unit of labor services for seven high-income countries (France, Germany, Italy, the Netherlands, Spain, UK, US) for various years, and three types of workers, distinguished by educational attainment (low, medium and high).

2.2. *The Flat Spot Range*

Bowlus and Robinson (2012) establish the flat spot range based on (cross-sectional) experience-earnings profiles. They conclude that, for high-skilled workers in the US, the flat spot occurs between the ages of 50 and 59. To infer the flat spot range for workers with lower levels of education, they choose the period at which those worker types would have the same length of (post-education) work experience, which means shifting the flat spot range back by three years for medium-skilled (so ages 47–56) and six for low-skilled (44–53) while keeping the length of the range at ten years.[10] The important question in our context is whether the US flat spot range is suitable for the other countries in the analysis. The flat spot range is the outcome of the workers' investment in human capital during the working life

[10]The US context typically distinguishes groups "with some college" and "high school graduates," but we group these together for the three-category breakdown more prevalent in international research. Sensitivity analysis for the US shows that this compression of the educational categories does not lead to qualitatively different results; results are available upon request.

and an optimizing worker would endogenously choose to stop investing in human capital as the end of the working life approaches. This means that the flat spot range in a country will be affected by the (expected) retirement age of a person. These differ across countries suggesting that the flat spot needs to be adjusted accordingly, as earlier retirement decreases the length of the working life and affects investment in human capital through on-the-job training (Jacobs, 2014).

To account for differences in the expected retirement age across countries, we adjust the flat spot range using information on the effective age of retirement among males. The OECD defines this as "the average effective age at which older workers withdraw from the labor force."[11] This differs from the official age of retirement (which does not show much variation across the countries of our sample) and better captures retirement expectations. Table 1 below shows the median effective age of retirement among males in the seven countries over the period 1990-2012 (OECD, 2013).[12]

We know already the flat spot range of the US from Bowlus and Robinson (2012). We retain the assumptions that the flat spot (a) lasts for a period of ten years[13] and (b) that it occurs earlier for those with a lower education level. We calculate the distance between the median value of the US high-skilled flat spot (54.5) and the retirement age (64.7) and observe that the high-skilled people reach the middle point of their flat spot range approximately ten years before retirement. We assume that the same distance applies to the other countries, identify the middle point of their high-skilled flat spot and the respective upper and lower bound and move the flat spot back accordingly to determine its range for the low- and medium-skilled.[14] Table 1 presents the results by country and level of education (low, medium, high). These are the country-specific flat spot ranges we subsequently use for the calculation of the price per unit of labor services and, although not very different between countries, they provide us with a consistent country-ranking based on retirement patterns.

The flat spot ranges we have determined are assumed constant over time. This means that we assume that, in the period under examination, the effective age of

TABLE 1
Effective Age of Retirement and the Flat Spot Across Countries

		Flat Spot		
	Retirement Age	Low-skilled	Medium-skilled	High-skilled
United States	64.7	44-53	47-56	50-59
France	59.3	39-48	42-51	45-54
Germany	61.2	40-49	43-52	46-55
Italy	60.8	40-49	43-52	46-55
Netherlands	61.0	40-49	43-52	46-55
Spain	61.6	41-50	44-53	47-56
United Kingdom	62.8	42-51	45-54	48-57

Source: Effective retirement age: OECD (2013). Flat spot range United States: Bowlus and Robinson (2012); other countries: own calculations.

[11]*Source*: https://www.oecd.org/els/emp/average-effective-age-of-retirement.htm

[12]For Germany, the data begin in 1996.

[13]Using a flat spot of five years for the US (for example, 55-59 for high-skilled workers) produces prices series that are highly correlated with those using a flat spot of ten years.

[14]The numbers are rounded to the closest integer to best capture the age range.

retirement has not changed sufficiently to affect decisions on investment in human capital. Indeed, the data show that the effective retirement age in the countries of the sample has remained rather stable, with only a slow upward trend after 2006. Assuming that human capital investment patterns change gradually after changes in retirement patterns, we do not expect that the modest increase in the effective retirement age affects our flat spot identification in the time frame we are focusing on.

2.3. *Data*

The data we use in order to calculate the price per unit of labor services are from the Luxembourg Income Study Database (LIS, 2012) for the six European countries in our analysis—France, Germany, Italy, the Netherlands, Spain, and the UK. Data for the US are drawn from the US Current Population Survey, as made available through IPUMS-CPS.[15] LIS collects and harmonizes survey data on socio-demographic and labor market characteristics, as well as income, at both the individual- and household-level.[16] Data are available for forty-nine countries over multiple years between 1967 and 2014.

We focus on six European countries over the 1990–2013 period, prioritizing the larger European countries.[17] In processing these data, we have taken special care to ensure consistency over time in variable definitions, to ensure comparability across countries and over time. Table 2 lists the main LIS variables we employ alongside a short definition.

The sample we analyze in order to construct the prices per unit of labor services consists of men of an age that falls within the country-specific flat spot range we have identified. Following Bowlus and Robinson (2012), females are excluded because of the fluctuations in their labor force participation. The self-employed are excluded as well. Furthermore, we only keep those employed full-time, full-year with a positive income (larger than or equal to one). As full-time full-year, we define those with at least thirty-five weekly hours and forty annual weeks worked. Income variables are deflated using the consumer price index and (for euro area countries) converted to euros for the full period. The hourly wage is constructed using information on the annual paid employment income (**pmile**) and a person's weekly hours (hours) and annual weeks (weeks) worked.[18]

Based on a person's completed level of education (**educ**), we derive prices for three categories of workers, as defined in Table 2. We calculate the median hourly wage by age and education level, and subsequently its log change between two points in time. Based on the methodology outlined above (equation 3), we then infer changes in the price per unit of labor services. A limitation of the LIS data is that it does not provide an annual series of surveys. We can directly implement the procedure from equation (3) for the United States, and thus have nine changes in

[15]See Flood et al. (2015); this allows us to have an annual time series covering the period since 1975.

[16]LIS uses as data sources national surveys such as the German Socio-Economic Panel (GSOEP) and the UK's Family Resources Survey (FRS).

[17]Expanding the set of countries would lead to shorter time coverage, since complete information on the required variables is typically a problem, especially when moving back in time.

[18]For the UK, data on the number of weeks worked is missing, so "full-year" employment cannot be used as a criterion and we can only divide the overall employment income by weekly hours.

TABLE 2
List of lis Variables and Definitions

LIS variable	LIS variable definition
age	Age in years
sex	Sex
educ	Highest completed education level This variable is recoded into three categories: (a) low: less than secondary education completed (never attended, no completed education or education completed at the ISCED levels 0, 1 or 2) (b) medium: secondary education completed (completed ISCED levels 3 or 4) (c) high: tertiary education completed (completed ISCED levels 5 or 6)
pmile	Paid employment income Monetary payments received from regular and irregular dependent employment
hours	Weekly hours worked, any information Regular hours worked at all jobs currently held (including family work and overtime, whether paid or unpaid)
weeks	Annual weeks worked, any information Number of weeks worked during the year in any job
emp	Employed Dummy that distinguishes the employed from the non-employed
status1	Status in employment (in first job) Variable that distinguishes the dependent-employed from the self-employed

Source: Documentation-LIS (available online at: https://www.lisdatacenter.org/wp-content/uploads/our-lis-documentation-variables-definition.xlsx)

wages to average over the flat spot range. For the European countries, there is a survey in (for instance) 1993 and 1999 for the Netherlands,[19] which means that rather than comparing the wage of a 49-year old to that of a 50-year old in the next year, the comparison is between a 49-year old in 1993 and a 55-year old in 1999. Since the data for the United States are available annually from the CPS, but also at similar intervals in the LIS data, we use a comparison between calculations based on the two sources to establish that the price series based on gaps in survey coverage are comparable to those based on annual survey data.

In the UK, data on the variable **educ** are missing for the year 1994, but not for other years in our analysis. We do have information on an individual's age when completed education for 1994, as well as in other years.[20] To incorporate data for 1994 in the analysis, we identify the typical education level at a given age of education completion. Based on this, we find that low-skilled workers are those who complete their education at or before the age of 15, medium-skilled between ages 16 and 20 and high-skilled are those who complete their education after age 21.

3. RESULTS

3.1. *The price and quantity of labor services per hour worked—United States*

An important outcome of our analysis is estimates of the price per unit of labor services for workers of different educational backgrounds. Bowlus and

[19]See Appendix Table A1 for the list of LIS surveys per country that we use in our analysis.
[20]"When he/she last attended continuous full-time education," variable **edcage** in LIS.

Robinson (2012, Figure 3) find that, in the US, the price per unit of labor services evolves similarly for each skill level, which leads them to conclude that changes in relative wages between skills levels represent (primarily) changes in the relative quantity of labor services per hour worked, rather than changes in relative prices. In Table 3, we show that our own calculations for the US provide a perspective that is not notably different. The first line shows our estimates for the 1975–2014 period, the full length of our study period for the US. While the price of high-skilled units of labor services has declined by less than that of medium- and low-skilled labor services, this is not a persistent difference.[21] The second line shows estimates based on the annual CPS data for 1991–2013, which corresponds to the period for which LIS data are available. The third line shows results based on LIS data for the 1991–2013 period.

The LIS data, for both the US and Europe, are not available annually but at intervals of typically three or four years, so lines two and three are useful to gauge the impact of annual data vs. multi-year gaps in the time series. The main difference is that the computation of price changes (equation (3)) can use fewer wage changes if there are gaps in the time series. For example, with annual data, the wage of 50-year old high-skilled workers in year 1 can be compared to 51-year old high-skilled workers in year 2, all the way to 58-year olds in year 1 and 59-year olds in year 2. As a result, the price change is based on the average of nine wage changes ($N = 9$ in equation (3)). In contrast, if wages are observed in year 1 and next in year 4, the price change is an average of 7 wage changes ($N = 7$ in equation (3)), comparing 50 year old to 53 year old high-skilled workers until 56 year old to 59 year old workers. There is no reason to suspect that this would impart a systematic bias to the price change estimates, but comparing lines 2 and 3 in Table 3 allows us to verify this. For low-skilled and high-skilled workers, the differences are small; for medium-skilled workers the differences are larger. Yet, as we show in Appendix Figure A1 by charting the full time series for the three skill levels, this larger difference is not a sign of a systematic deviation between the two sources but a one-off outlier. This gives us greater comfort in relying on LIS data for the analysis of the European countries, below. At the same time, the results in Table 3 (as well as those for the European countries, in Table 5 below) suggest that the conclusion of "no relative price changes" by Bowlus and Robinson (2012) seems not warranted in general. So while Bowlus and Robinson (2012) disregard relative price movements when analyzing changes in the quantity of labor services per hour worked, we will use the observed price changes from Table 3 (and Table 5) when decomposing the overall wage into a price and quantity component, as in equation (1).

Figure 2 shows the quantity of labor services per hour worked in the US between 1975 and 2014, computed by dividing the median wage of (full-time, full-year male) workers between the ages of 26 and 60 of a given educational attainment by the price per unit of labor services for that level of educational

[21]Our results also closely match those of Bowlus and Robinson (2012, Figure 3).

attainment, i.e. by applying equation (1). The figure shows the annual series (solid line) as well as an estimate of the longer-run trend, computed using a LOWESS smoother with a bandwidth of 0.5.[22] The labor services per hour worked of high-skilled workers increased substantially over this period, rising by 25 percent compared to 1975, with most of this increase (19 percent) occurring between 1995 and 2005. There has been a decline in labor services per hour worked of medium-skilled workers of approximately 10 percent, with a sustained decline between 1975 and 1995 and fluctuations around this level in the subsequent period. Labor services per hour worked of low-skilled workers also declined, by 20 percent, with sustained declines between 1975 and 1995. This periodization is somewhat arbitrary, also given the, sometimes large, year-to-year fluctuations in the series. The estimated trends suggest that salience of the 1975–1995 period for medium- and low-skilled workers and of the 1995–2005 period for high-skilled workers may not be as large, but notable differences remain in the pattern of changes over time.

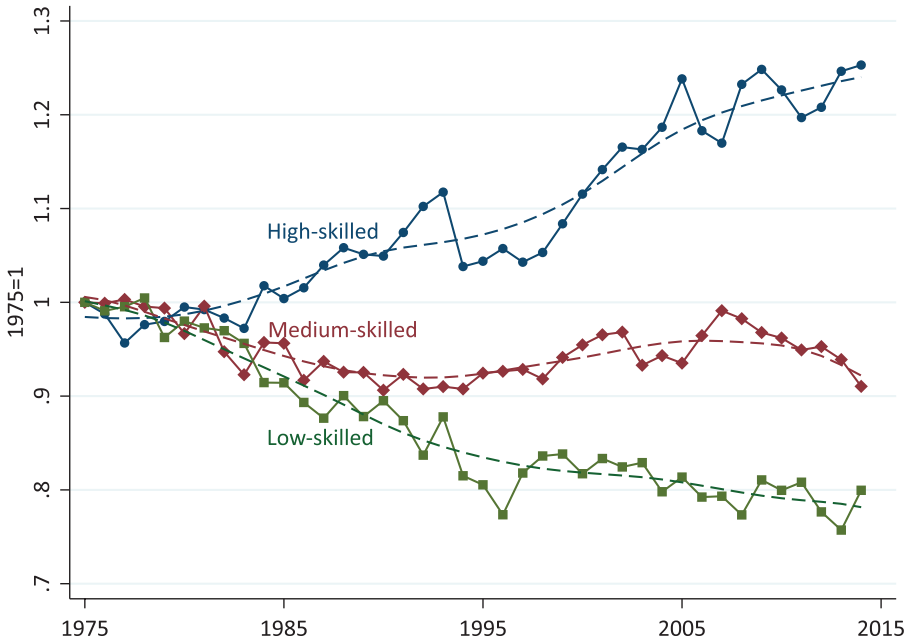

Figure 2. Labor Services per hour Worked in the United States, 1975–2014.
Source: Computations based on CPS data from IPUMS-CPS (Flood et al., 2015).
Notes: The solid lines show the annual time series of labor services per hour worked, the dashed line is the LOWESS trend estimate (bandwidth of 0.5). Labor services per hour worked are computed by dividing the median wage of full-time, full-year male workers between the ages of 26 and 60 of a given educational attainment by the price per unit of labor services of that educational level (see Table 3) and normalized to one in the initial year, 1975. [Colour figure can be viewed at wileyonlinelibrary.com]

[22]The LOWESS smoother creates a curve to best capture the trend of labor services per hour worked. It is the result of a locally weighted regression of labor services per hour worked on time/year.

TABLE 3
THE CHANGE IN THE PRICE PER UNIT OF LABOR SERVICES IN THE UNITED STATES

		Change in the price per unit of labor services		
Source	Period	Low-skilled	Medium-skilled	High-skilled
CPS	1975-2014	-0.24	-0.20	-0.18
CPS	1991-2013	-0.01	-0.11	-0.06
LIS	1991-2013	-0.02	-0.18	-0.04

Source: Computations based on LIS data (LIS, 2017) and CPS data from IPUMS-CPS (Flood et al., 2015).

Notes: The price per unit of labor services is computed based on equation (3) and the flat spot ranges in Table 2. Each entry in the table indicates the change in price over the stated period, relative to the change in the country's consumer price index.

TABLE 4
LINEAR TIME TREND OF LABOR SERVICES PER HOUR WORKED IN THE UNITED STATES, 1975–2014

	Low-skilled	Medium-skilled	High-skilled
Age 26-60	-0.0067***	-0.0007	0.0069***
	(0.0004)	(0.0004)	(0.0003)
Age 26-35	-0.0044***	-0.0015**	0.0052***
	(0.0007)	(0.0007)	(0.0004)
Age 36-45	-0.0058***	-0.0025***	0.0056***
	(0.0005)	(0.0003)	(0.0005)

Notes: N=40. Each entry in the table is the coefficient of a linear time trend on the log of labor services per hour worked in a given age range and level of educational attainment. Robust standard errors are given in parentheses; $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

To establish that the patterns in Figure 2 are not mere noise in a statistical sense, the first row of Table 4 shows the coefficients of a linear time trend for the (log of) labor services per hour worked for the age range 26 to 60. This shows a significant negative time trend for low-skilled workers, no significant time trend for medium-skilled workers, and a positive time trend for high-skilled workers. The subsequent rows test the sensitivity of this result and show that similar time trends can be observed for narrower age ranges, though with a significantly negative time trend for medium-skilled workers as well. This indicates that the patterns are observed broadly across the (male) population.

3.2. *The price and quantity of labor services per hour worked—Europe*

We next turn to the European countries, analyzing the trends in relative price and then quantities of labor services. The price developments, shown in Table 5, are more mixed than in the US, with, for example, France showing similar price trends across educational categories, Germany showing price declines for low-skilled and price increases for high-skilled and the UK showing the reverse pattern of price increases for low-skilled and price decreases for high-skilled labor services. This variety of patterns remains intact through a range of sensitivity checks (see below) and does not lend itself to easy explanation. This more firmly

TABLE 5
THE CHANGE IN THE PRICE PER UNIT OF LABOR SERVICES IN EUROPE

		Change in the price per unit of labor services		
Country	Period	Low-skilled	Medium-skilled	High-skilled
France	1994-2005	0.12	0.17	0.14
Germany	1994-2013	-0.15	0.07	0.36
Italy	1991-2010	0.04	0.01	0.12
Netherlands	1990-2013	0.07	0.06	0.13
Spain	2007-2013	-0.01	0.15	0.10
United Kingdom	1994-2013	0.11	-0.24	-0.27

Source: Computations based on LIS data (LIS, 2014).
Notes: The price per unit of labor services is computed based on equation (3) and the flat spot ranges in Table 2. Each entry in the table indicates the change in price over the stated period, relative to the change in the country's consumer price index.

establishes the need to account for these price changes when analyzing the trends in the quantity of labor services per hour worked.

To analyze the trends in the quantity of labor services per hour worked across European countries, we first pool the country-level results. We compute a weighted average across the six European countries of labor services per hour worked, first linearly interpolating between LIS-covered years and then using the share of each country in total employment by educational attainment as weights.[23] Due to variation in country coverage over time, we construct a "Europe" series starting in 1994 and ending in 2013.

Figure 3 shows the development of the quantity of labor services per hour worked for the six European countries, on the same scale as Figure 2 for the US. There is no clear trend over time in the quantity of labor services per hour worked for any level of educational attainment. This is especially true when taking the year-to-year swings into account, i.e. it is hard to discern a trend if an increase or decrease of 6 percent in labor services per hour worked can be observed.[24] This is further confirmed in Table 6, which shows the results from regressions of a linear time trend on the log of labor services per hour worked for all observations for the six European countries. The regressions include country fixed effects as the period covered in each country differs (though results are not substantively different without fixed effects).[25] The only common finding across age groups is that labor services per hour worked of low-skilled workers have declined, though the rate of decline is smaller than observed in the US (see Table 4).

[23]Using data from the WIOD Socio-Economic Accounts (Timmer et al. 2015), we assume that workers in the UK work 40 weeks per year to accommodate missing data on this variable in LIS.

[24]Although there seem to be increases in recent years (after the Great Recession), these may be (at best) the start of a longer trend rather than an established pattern. Moreover, there is no difference by skill level, so even if this were a clear trend, it would be one of a different pattern.

[25]Omitting France and Spain from the sample (since data for these countries are scarce and Spanish series only begin in 2007) produced regression results similar to those of Table 7.

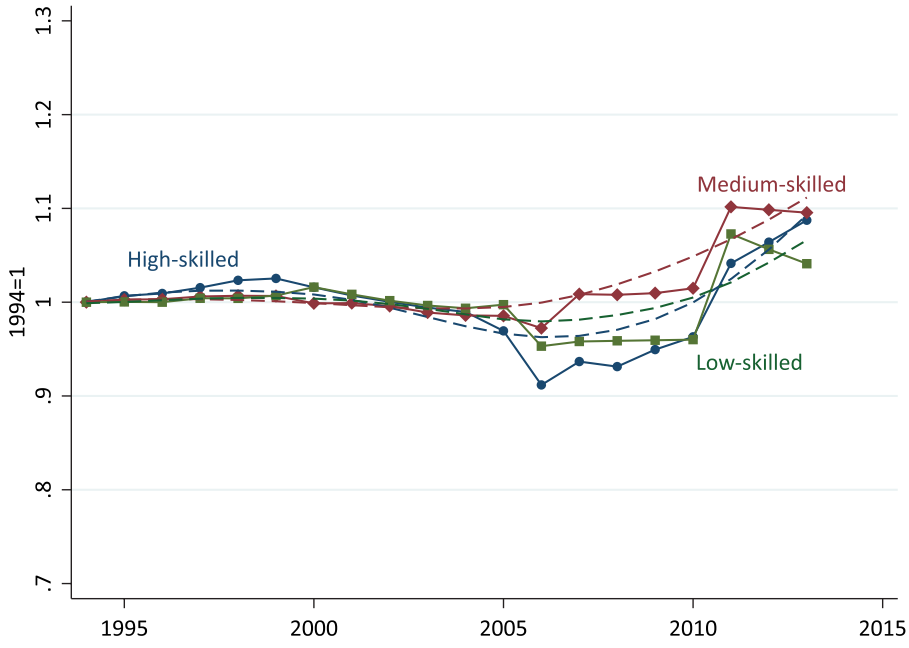

Figure 3. Labor Services per hour Worked in Europe, 1994–2013.

Source: Computations based on LIS data (LIS, 2017).

Notes: The solid lines show the annual time series of labor services per hour worked, the dashed line is the LOWESS trend estimate (bandwidth of 0.5). Labor services per hour worked are computed by dividing the median wage of full-time, full-year male workers between the ages of 26 and 60 of a given educational attainment by the price per unit of labor services of that educational level (see Table 5) and normalized to one in the initial year, 1994. The figure shows a weighted average of labor services per hour worked across the six European countries covered (see Table 5), using total employment by educational attainment of a country as weights. [Colour figure can be viewed at wileyonlinelibrary.com]

Despite these inconclusive patterns for the period as a whole and the full set of European countries, a clearer distinction becomes apparent when zooming in on the period of 1995 to 2005. For the United States, this was the period in which the largest increases in labor services per hour worked by high-skilled workers could be seen, in Figure 2, and this is shown in the first line of Table 7. When selecting the LIS survey years of each European country to most closely match the 1995–2005 period,[26] the UK stands out amongst the European countries in showing a 25 percent increase in labor services per hour worked by high-skilled workers, while the four Continental European countries show declines of 10 to 14 percent. For low-skilled and medium-skilled workers the changes in the quantity of labor services per hour worked are typically smaller than for high-skilled workers, though the UK also shows a notable increase for medium-skilled workers. Before turning to a discussion of what may be driving these differences for high-skilled workers and to the implications of these differences for measured productivity, we first assess the sensitivity of the results to the assumptions and choices we made.

[26]Spain is not shown in the table because its price series is only available from 2007 onwards, see Appendix Table A1.

TABLE 6
Linear Time Trend of Labor Services Per Hour Worked in Europe, 1990–2013

	Low-skilled	Medium-skilled	High-skilled
Age 26-60	-0.0026*	0.0000	-0.0033
	(0.0012)	(0.0027)	(0.0037)
Age 26-35	-0.0062**	-0.0035	-0.0084*
	(0.0022)	(0.0036)	(0.0039)
Age 36-45	-0.0041**	-0.0019	-0.0036
	(0.0011)	(0.0022)	(0.0040)

Notes: N=33. Each entry in the table is the coefficient of a linear time trend on the log of labor services per hour worked in a given age range and level of educational attainment. All 33 observations as well as country fixed effects for the six European countries are included in each regression. Robust standard errors are given in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

3.3. *Sensitivity Analysis*

Computing the prices per unit of labor services involves a series of choices and judgements, as the preceding discussion has already illustrated. Of particular note is the determination of the flat spot range. Bowlus and Robinson (2012) devote considerable attention to this topic, for instance by showing that moving the flat spot range for high-skilled workers to earlier ages would pick up some of the upward-sloping wages in a standard, concave earnings-experience profile. We have anchored our own analysis to that of Bowlus and Robinson (2012) by using their US flat spot range and adjusting it to reflect differences in effective retirement age. An alternative is to directly use the US flat spot range for European countries.

In addition, we consider a range of treatments of the European LIS data. What our results for the US (Table 3) already indicated is that the frequency of survey data availability is not an important source of sensitivity, nor is the number of educational categories considered (four in Bowlus and Robinson, 2012, three in this study). A potential concern could be that the price series we estimate are "contaminated" with noise. A reason could be a small number of full-time full-year male survey respondents in an education/age cell, which could give wage outliers an undue influence on the final price series. By taking the median wage of each education/age cell, we already limit the scope for such outlier-induced noise.

In this sensitivity analysis, we consider three additional approaches. The first is to trim the top and bottom 2.5 percent of wages in the entire flat spot range (e.g. US high-skilled workers between the ages of 50 and 59)[27]. The other two are computed using only wage information for workers within industry (manufacturing, construction) or only within services[28] as shifts between sectors could conceivably skew the results. Finally, we explore to what extent the results are influenced by the selection of only (male) workers that work full-time for a full year. As an

[27]We only trim wages in the flat spot range because trimming the entire wage distribution for the computation of changes in the quantity of labor services per hour worked would not affect the median wage of workers aged 26-60. The trimming in the flat spot range does have an effect because observations that are dropped will belong to different age cells (at a given level of education).

[28]A more fine-grained industrial classification was not feasible. As it is, the number of observations per age/education/sector cell sometimes makes computation of sensible price series infeasible. For one-off occurrences, we use the baseline price trend. For France and Italy, it is not possible to compute price change for the full period due to missing industry classifier variables.

TABLE 7
The Change in the Quantity of Labor Services Per Hour Worked in Europe and the United States between the mid-1990s and mid-2000s

		Change in the quantity of labor services per hour worked		
		Low-skilled	Medium-skilled	High-skilled
United States	1995-2005	0.01	0.01	0.19
United Kingdom	1994-2004	-0.09	0.22	0.25
France	1994-2005	-0.04	-0.10	-0.14
Germany	1994-2004	0.01	-0.04	-0.10
Italy	1995-2004	0.00	0.00	-0.09
Netherlands	1993-2004	0.02	0.02	-0.10

Notes: See Notes to Figures 2 and 1. Spain is not shown because its data series starts in 2007.

"unrestricted" alternative, we compute prices based on the sample of male workers that work at least 5 weekly hours and 5 weeks per year. In Table 8, we show how the baseline results in the final column of Table 7 change for these alternatives.[29]

As the table shows, the different price series influence the change in the quantity of labor services per hour worked relative to the baseline estimate. Yet the overall pattern remains similar: the US and UK show increasing labor services per hour worked for high-skilled workers, while the Continental European countries show predominantly declines. Relying on the US flat spot range rather than our country-specific ranges has a varied impact on the Continental European countries, with larger declines in France but even a small increase in the Netherlands. Selecting workers only in Industry or in Services leads to somewhat smaller changes in the quantity of labor services per hour worked in some of the countries, but again, no substantive changes. Outliers in wage data do not seem to have a systematic impact as the change in the quantity of labor services per hour worked for the Trimmed series is barely different from the baseline. Finally, using a less restrictive sampling of workers to compute the change in price of labor services per hour worked leads to somewhat larger changes, but again, no substantial deviation from the baseline results.

3.4. *Discussion of cross-country differences*

The patterns in Table 7 are based solely on observed wage changes of workers at different age and educational qualifications. By itself, this provides no indication why particular patterns are observed in some countries but not in others – a common problem in this literature, see e.g. Bowlus and Robinson (2012) and Lagakos et al. (2018). That said, it is possible to contrast some explanations. First, recall that in Figure 2, the fastest increase in wages of high-skilled workers in the US between 1995 and 2005 was observed in the middle of the age distribution, between approximately the age of 35 and 50 (see also Table 9). One set of explanations of vintage effects rests on the quality of students and the quality of (higher) education. For example, if a greater share of high-school graduates go on to attend university without an increase

[29]The estimates for low and medium-skilled workers do not show a clear pattern and are therefore omitted. These data are available on request.

TABLE 8
SENSITIVITY ANALYSIS FOR THE CHANGE IN LABOR SERVICES PER HOUR WORKED FOR HIGH-SKILLED WORKERS IN EUROPE AND THE UNITED STATES BETWEEN THE MID-1990S AND MID-2000S

		Baseline	US flat spot	Industry	Services	Trimmed	Unrestricted
United States	1995-2005	0.19	0.19	0.18	0.16	0.18	0.21
United Kingdom	1994-2004	0.25	0.15	0.23	0.19	0.23	0.30
France	1994-2005	-0.14	-0.34	n.a.	n.a.	-0.15	-0.15
Germany	1994-2004	-0.10	-0.13	-0.09	-0.09	-0.09	-0.05
Italy	1995-2004	-0.09	-0.06	n.a.	-0.03	-0.07	-0.11
Netherlands	1993-2004	-0.10	0.03	-0.23	-0.03	-0.08	-0.13

Notes: The baseline column corresponds to the final column of Table 8. "US flat spot" uses the flat spot range for the US from Table 2 instead of country-specific flat spot ranges. 'Industry' and 'Services' estimates prices using only wage information of workers in those particular sectors, which eliminates any impact of pay differentials between broad sectors. "Trimmed" removes the top and bottom 2.5 percent of wage information in the entire flat spot range before computing the prices for labor services as in equation (3). "Unrestricted" includes all (male) workers with at least 5 weekly hours worked and 5 weeks worked per year, rather than the full-time, full-year restriction. Missing estimates for "Industry" or "Services" are due to missing industry classifier variables or lack of observations.

TABLE 9
Wage Change of High-Skilled Workers by Age Group (in %)

Country	Period	Young	Middle	Old
United States	1995-2005	6.2	12.6	-1.2
United Kingdom	1994-2004	4.9	6.1	1.9
France	1994-2005	-3.2	3.0	0.0
Germany	1994-2004	5.5	21.4	27.6
Italy	1995-2004	3.4	-7.8	-0.7
Netherlands	1993-2004	5.2	13.6	8.5

Notes: The figures in the table are based on the log median wage of high-skilled workers at each age at the start and end of the period shown. The young are workers aged 26–35, the middle are 36 to the start of each country's flat spot range and the old are workers in the flat spot range (see Table 2).

in the cognitive and non-cognitive skills of these graduates, then we may see a decline in the average human capital of university graduates. Alternatively, if universities deliver a higher-quality education, then we would expect to see university graduates with higher levels of labor services per hour worked. In both cases, though, we would expect that these changes would manifest early in those workers' careers.

An alternative explanation focuses on changes in workers' "human capital production function": newer vintages of workers may be able to more rapidly improve their own human capital with experience or on-the-job training. This explanation is consistent with the observed pattern of more rapid wage increases of US high-skilled workers in the middle of the age distribution: their human capital is similar at the start of their careers, but grows more rapidly than that of previous cohorts as they gain more experience. A more specific argument would be that especially in the 1995 to 2005 period, ICT diffused extensively. Given that ICT is complementary to high-skilled workers (e.g. Michaels et al., 2012), the increased spread of ICT will have improved the productivity of high-skilled workers. ICT may also have improved the productivity of younger workers more than of workers in the flat spot range, since workers in the flat spot range are no longer investing in improving their human capital, for instance by learning to work with ICT. There is some support for this in the OECD's PIAAC study of adult competencies: based on the micro data, we find that younger workers score higher on tests of problem-solving in IT-rich environments.

Yet this still leaves unexplained why university graduates in the US and UK have improved human capital production functions and those in Continental European countries have not. To that end, Table 9 summarizes the wage change by age group for each country over the same period as highlighted in Table 7. The three age groups are defined to match the main differences shown for the US in Figure 2, but a different periodization would not lead to different results. For the US, the table shows that "old" workers, i.e. those in the flat spot range (50–59 for the US, see Table 1) saw some wage declines.[30] The young, aged between 26 and 35

[30]Note that these wage changes are computed on the actual observed log median wages, while Figure 2 uses a LOWESS smoother, where each point in the graph is based on nearby observations for the unsmoothed data. This explains why Figure 2 implies a small increase for US high-skilled workers in the flat spot range while the table shows a small decrease.

saw clear increases, while those in the middle of the age distribution, aged 36 to 49 in the case of the US, saw the strongest gains. In the UK a similar pattern can be observed, though the difference between the young and those in the middle of the age distribution is not as pronounced.

In Continental European countries, the picture is more mixed. Older workers (i.e. those in the flat spot range) saw little to no change in their wage in France and Italy, but younger workers (in France) and middle-aged workers (in Italy) saw decreases. In Germany and the Netherlands wages increased across all age groups, which in the Bowlus and Robinson (2012) method contributes to rising prices of labor services of high-skilled workers. Though this pattern is mixed, it is consistent with an argument that ICT had a stronger impact on worker productivity in the UK and US, which invested considerably more in these technologies than the countries in Continental Europe (see, e.g. van Ark et al., 2008). Of course, we cannot and do not claim that this is the only argument consistent with these results.

3.5. *Implications for Europe-US productivity growth comparisons*

Our main finding is that labor services per hour worked of high-skilled workers in the US and UK increased by 19–25 percent between 1995 and 2005, while Continental European countries register declines of 10–14 percent over the similar period. This is a finding that can have important implications for productivity growth comparisons between Europe and the US. Standard growth accounting assumes constant labor services per hour worked over time in estimating (multifactor) productivity growth, but if this assumption is violated, productivity growth will have been overestimated in the US and UK and underestimated in Continental European countries. Between 1995 and 2005, productivity growth in the US was much higher than before or since (Byrne et al., 2016; Syverson, 2016) and much higher than in Europe (e.g. van Ark et al., 2008). If we zoom in on the market economy—which excludes government, health, education and real estate—US productivity growth was 1.4 percent on average per year between 1995 and 2005, while growth averaged a mere 0.6 percent between 1975 and 1995 and 0.1 percent between 2005 and 2014.[31] In contrast, European countries showed notably lower productivity growth over this period, see also 10, below. A large literature has aimed to explain this growth gap focusing on explanations such as lower investment in R&D and stricter regulations or the role of ICT-producing and ICT-using industries; see e.g. the survey of Ortega-Argilés (2012). Yet our analysis points to a hitherto underappreciated element. While differences in human capital accumulation have typically been found wanting as an explanatory factor, relaxing the "constant labor services per hour worked" assumption may provide greater heft to this factor.

To gauge the importance of our findings for the Europe-US productivity growth difference, consider the following expression for (Solow residual) productivity growth:

[31]The 1975–2005 data are drawn from the 2012 version of the EU KLEMS database; see O'Mahony and Timmer (2009). The 2005–2014 average is computed using BLS data for the private business sector, which showed similar growth as the EU KLEMS market economy between 1995 and 2005.

TABLE 10
THE IMPACT OF CHANGES IN THE QUANTITY OF LABOR SERVICES PER HOUR WORKED BY HIGH-SKILLED ON PRODUCTIVITY GROWTH IN EUROPE AND THE US, AVERAGE ANNUAL GROWTH 1995–2005

	Standard growth accounting			Adjusted for vintage effects		
	High-skilled	Total labor	TFP growth	High-skilled	Total labor	TFP growth
United States	1.9	1.0	1.3	3.7	1.7	0.8
United Kingdom	4.2	1.2	1.0	6.6	1.9	0.5
France	4.4	1.3	0.8	2.9	0.8	1.1
Germany	1.5	-0.5	0.7	0.5	-0.9	0.9
Italy	7.1	1.3	-0.6	6.0	1.2	-0.5
Netherlands	5.9	1.3	0.9	4.9	1.1	1.1
Spain	8.8	4.1	-0.8	7.6	3.8	-0.6

Sources: Growth in high-skilled hours worked and the share in total labor compensation from the WIOD Socio-Economic Accounts (Timmer et al., 2010); TFP growth from the EU KLEMS 2012 version (O'Mahony and Timmer, 2009).

Notes: High-skilled labor input growth under standard growth accounting is the average annual growth of hours worked by high-skilled; adjusted for vintage effects uses the average annual change in the quantity of labor services per hour worked of high-skilled workers from the final column in Table 8 to adjust the trends in hours worked. For Spain we assume the same change in the quantity of labor services per hour worked as for Italy. Total labor input under standard growth accounting is based on equation (5); adjusted for vintage effects is based on equation (6). TFP growth is based on equation (4) for standard growth accounting; adjusted for vintage effects is based on equation (4').

$$\Delta \log A = \Delta \log V - \alpha \Delta \log K - (1-\alpha)\Delta \log L \tag{4}$$

where Δ is the difference operator, A is productivity, V is value added, K is capital input, L is labor input, and α is the output elasticity of capital—typically assumed to be equal to the share of capital income in value added. This implies assuming perfect competition in factor and output markets and a constant returns to scale production function. Labor input is typically distinguished by type of worker, assuming that a given type of worker (denoted by j) provides a constant quantity of labor services per hour worked over time. If that type of worker's marginal product equals its marginal cost, the share of total labor compensation flowing to that type of worker (w_j) can be used to weight the growth in hours worked by that type of worker, H_j:

$$\Delta \log L = \sum_{j=1}^{N} w_j \Delta \log H_j \tag{5}$$

But if, as we have established, the effective labor input per hour worked of a particular type of worker changes over time, we should adjust our computation of the growth in overall labor services:

$$\Delta \log L^* = \sum_{j=1}^{N} w_j \Delta \log \left(H_j \times E_j \right) \tag{6}$$

Here E_j is an estimate of effective labor services per hour worked. Note that the labor compensation share w_j of each labor type is the same in both equations, as total labor compensation does not depend on the division of that sum between a price and a quantity component. Denote as $\Delta \log A^*$ the estimate of productivity growth based on adjusted growth in labor services, so substituting $\Delta \log L$ by $\Delta \log L^*$ in equation (4):

$$\Delta \log A^* = \Delta \log V - \alpha \Delta \log K - (1-\alpha)\Delta \log L^* \tag{7}$$

To implement equations (5) and (6), we use data on hours worked (H_j) and the share of labor compensation (w_j) of low-, medium-, and high-skilled workers for the United States and the six European countries.[32] All E_j are set equal to one, except for those of high-skilled workers between 1995 and 2005. For those years and that type, we set the annual E_j such that the quantity of labor services per hour worked by high-skilled workers increases by the amount shown in the final column of Table 7. This assumes that our estimates of the increase in labor services per hour worked of (full-time, full-year) male workers is applicable for all workers. As discussed in Bowlus and Robinson (2012), this may be an overestimation, because

[32]These data are not available in the 2012 version of EU KLEMS, but are presented in WIOD's Socio-Economic Accounts (Timmer et al. 2015), so we use those data and combine them with TFP growth estimates from EU KLEMS. Also note that these shares are not constant over time, so we compute two-period average compensation shares to implement equations (5) and (6) as a Törnqvist index. Similarly, we use the two-period average share of capital income in value added in implementing equations (4) and (4').

of changes in the degree of discrimination of women in the labor market. Such changes, though, may be relatively modest over a ten year period.

Table 10 presents standard growth accounting results based on EU KLEMS as well as figures adjusted for the vintage effects for high-skilled workers that we found in Table 7 for the period 1995 to 2005. The average annual growth of high-skilled labor input is shown first, with changes in total hours worked shown under "Standard growth accounting" and changes in total labor services under "Adjusted for vintage effects". So, for example, total hours worked of high-skilled workers grew at an average annual rate of 1.9 percent in the US over this period. The final column in Table 7 showed that labor services per hour worked of US high-skilled workers increased by 19 percent over this 10-year period, which corresponds to an average annual increase of 1.8 percent. Therefore, labor services of high-skilled increased at an average annual rate of 3.7 percent, as shown under "Adjusted for vintage effects". We can then apply equations (5) and (6) to show that total labor services grew 0.7 (1.7-1.0) percentage points faster when adjusting for vintage effects than based on standard growth accounting assumptions.[33] This translates to an average annual TFP growth of 0.8 percent when adjusting for vintage effects versus 1.3 percent under standard growth accounting.

Under standard growth accounting assumptions, the US showed notably faster TFP growth between 1995 and 2005 than the Continental European countries, and the United Kingdom also had a growth advantage. Within Continental Europe, the performance of Italy and Spain is notable, with declines in productivity. After adjusting for vintage effects, TFP growth in France and the Netherlands outstrips that of the other countries. Growth in the US and UK is slower than in Germany, though still higher than in Italy and Spain. As recently argued by Cette et al. (2016) and Gopinath et al. (2017), the productivity declines in Italy and Spain can be traced to a deterioration of the capital allocation process. That deterioration, in turn, was triggered by the decline in real interest rates in the run-up to Italy and Spain joining the euro. In other words, the productivity declines in these countries were due to exceptional circumstances, while the other five countries in the table had broadly comparable productivity growth rates between 1995 and 2005. This implies that the most notable difference between Anglo-Saxon and Continental European countries is in their human capital vintage effects.

This finding has implications for the distinction between embodied and disembodied technical change. If labor is not adjusted for vintage effects, embodied technical change will be mixed up with disembodied technical change by ending up in the residual, MFP. For the US and the UK, for example, we find that the role of disembodied technical change has been overestimated under standard growth accounting.

4. CONCLUSIONS

This paper has contributed to a growing literature that emphasizes human capital accumulation after formal education as an important factor for understanding the role of human capital in the process of economic growth and for understanding

[33]Labor compensation of high-skilled workers accounted for, on average, 31 percent of total labor compensation in the US over this period

cross-country income differences. In growth accounting (or development accounting) a standard assumption is that an hour worked by a worker of given type, e.g. high-skilled males, represents a constant amount of labor services per hour worked over time. Yet if there are vintage effects, this assumption may be violated. Our starting point is recent research that identified vintage (or cohort) effects for the US (Bowlus and Robinson, 2012) and we extended their methodology to six European countries. The starting point in their methodology is that the "constant labor services per hour worked" assumption only holds for workers in the later stage of their working life, when the incentive to invest in human capital has disappeared—the so-called flat spot range. Vintage effects can then be identified from wage changes for younger workers relative to wage changes of workers in the flat spot range.

We confirm the findings for the US of Bowlus and Robinson (2012) of vintage effects, with declining labor services per hour worked for low- and medium-skilled workers between 1975 and 1995 and rapidly increasing labor services per hour worked by high-skilled workers between 1995 and 2005. We find similar vintage effects in the UK from the mid-1990s to the mid-2000s, with even larger increases in labor services per hour worked by high-skilled workers. In contrast, we find evidence of declining labor services per hour worked by high-skilled workers in the Continental European countries, in a notable divergence.

This divergence in vintage effects has a notable impact on the productivity growth difference between the US and UK, on the one hand, and the Continental European countries—France, Germany, Italy, Netherlands and Spain—on the other hand. The increases of labor services per hour worked in the US and UK imply faster growth of labor input and, hence, smaller productivity growth. The opposite is the case for the Continental European countries. The net result of these adjustments is that the US and UK no longer show faster productivity growth than the Continental European countries.

The method we employ does not directly give insights into the reasons for why the vintage effects are so different between the Anglo-Saxon countries and those in Continental Europe. As we have argued, though, the pattern of wages changes by age group is consistent with an argument where rapid ICT investment from the mid-1990s onwards had a particularly beneficial effect on the productivity of high-skilled workers in the US and UK, which invested most heavily in these technologies. Establishing whether this was indeed the main factor is beyond the scope of this paper. We leave this important issue for future research.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web site:

Appendix

Table A1. Coverage of LIS survey years

Figure A1. Price series for the US based on CPS and LIS data for 1991 -2013