Vintage effects in human capital

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Vintage effects in human capital: Europe versus the United States*

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Abstract

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 productivity growth advantage of the US and UK, the primary difference with Continental European countries was human capital vintage effects instead.

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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, Ho and Samuels (2015, 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 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. 2010), but if vintage effects led to higher growth of (effective) labor input in the United States 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 United States, covering the 1975–2014 period (using data from the Current

[1] See Hulten (2010) for a more recent survey.
[2] Jones (2016, p. 11) shows very similar estimates.
[3] We use the term 'vintage effects' throughout, but the literature also refers to these as 'cohort effects'.

Population Survey, CPS) and for 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 workers is assumed to be constant over time. Observing an increase in workers' wages then automatically means 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 (in particular Ben-Porath, 1967) and earlier work by Heckman, Lochner and Taber (1998). The key assumption of Bowlus and Robinson (2012) is that changes in the price of human capital for a particular educational level can be identified only for workers at a late stage in their life cycle since these older workers no longer increase their productivity over time. Put differently, there is a period in a worker's life cycle during which worker productivity is constant, a so-called flat spot range. If wages of younger workers increase more rapidly than for workers (of the same educational level) in this flat spot, then the conclusion should be that the labor services per hour worked of these younger workers has increased. The Bowlus and Robinson (2012) method thus provides a time series of prices per unit of labor services for each educational level that can be compared to wages by educational level to track changes in the quantity of labor services per hour worked.

The main finding in Bowlus and Robinson (2012) is that, starting around 1980, wages of high-skilled workers in the United States 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 abor 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 of high-skilled work, this implies that standard growth accounting substantially underestimates

[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).

the contribution of improvements in human capital to US growth and overestimates the role of (multifactor) productivity growth, which is determined as a residual. Indeed the Bowlus and Robinson (2012) results indicate that uncounted human capital improvements may have been large enough to eliminate productivity growth entirely. The Bowlus and Robinson (2012) method does not reveal the underlying drivers of the changes in labor services per hour worked, but the authors mention that selection effects could play a role, whereby, for instance, the distribution of innate ability of college students has changed as enrollment has increased. Another possibility they mention is changes in the human capital production function, that would allow high-skilled workers to more rapidly accumulate human capital during their working life.

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.[5]

Within Europe, the United Kingdom's experience is most similar to that of the United States, 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 and the United States between 1995 and 2005, the topic of a sizeable literature.[6] Under standard growth accounting

[5] See e.g. Byrne, Fernald and Reinsdorf (2016) on the timing of US productivity growth episodes.
[6] See e.g. Ortega-Argilés (2012) for a survey or van Ark, O'Mahony and Timmer (2008) for a notable contribution.

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 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.[7] 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. However, the possible explanations for the vintage effects are probably less numerous than for differences in the (Solow residual) productivity growth measure. This would be an interesting avenue for future research.

In measuring vintage effects for human capital, this paper adds to a recent, growing literature on this topic. Lagakos et al. (2016) 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 (2014) 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

[7] See Gopinath, Kalemli-Ozcan, Karabarbounis and Villegas-Sanchez (2017) and Cette, Fernald and Mojon (2016).

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

Methodology

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 $\left(w_{t,i}\right)$ 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 $\left(q_{t,i}\right)$:

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

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

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

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 investment 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 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 of 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[8] are homogenous, so we can summarize the wage within each age-education cell as the median across all workers in this cell, denoted by $\widetilde{\log(w_{t,i})}$ for age i at time t. 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 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 $t = 0, \dots, T$ for labor services per hour worked can be computed as:

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

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 when data for adjacent years are available. We average across these wage differences to derive the price per unit of labor services.

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

Bowlus and Robinson (2012) estimate prices of labor services. Therefore, in the example above, we are comparing the (logarithm of the) median hourly wage of high-skilled (tertiary-educated) 51-year olds in year 2000 to the median hourly wage of high-skilled 52-year olds one year later. We estimate prices per unit of labor services for seven high-income countries (France, Germany, Italy, the Netherlands, Spain, UK, US) for various years between 1990 and 2013, and three types of workers, distinguished by educational attainment (low, medium and high).

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.[9] 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 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, 2010).

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 (2012) defines this as “the average effective age at which older workers withdraw from the labor force”. This differs from the official age of retirement (which does not show much

[9] 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.

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, 2012).

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 (2012). Flat spot range United States: Bowlus and Robinson (2012); other countries: own calculations.

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 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.[10] 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 retirement has not

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

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.

Data

The data we use in order to calculate the price per unit of labor services are from the Luxembourg Income Study Database (LIS, 2016) for the six European countries in our analysis – France, Germany, Italy, the Netherlands, Spain, and the United Kingdom. Data for the United States are drawn from the US Current Population Survey, as made available through IPUMS-CPS.[11] LIS collects and harmonizes survey data on socio-demographic and labor market characteristics, as well as income, at both the individual- and household-level. Data are available for forty-eight countries over multiple years between 1967 and 2013.

We focus on six European countries over the 1990-2013 period, prioritizing the larger European countries.[12] 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 below 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 employed with a positive income (larger than 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

[11] See Flood et al. (2015); this allows us to have an annual time series covering the period since 1975.
[12] 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.

information on the annual paid employment income (**pmile**) and a person's weekly hours (**hours**) and annual weeks (**weeks**) worked.[13]

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: http://www.lisdatacenter.org/wp-content/uploads/our-lis-documentation-variables-definition.xlsx)

Based on a person's completed level of education (**educ**), we derive prices for three categories of workers, as defined in the table. 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

[13] For the United Kingdom, 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.

nine changes in 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,[14] 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.[15] To incorporate data for 1994 in the analysis, we look for each educational level at the median age at which workers complete that level. 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.

Results

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 Robinson (2012, Figure 3) find that, in the United States, 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 United States. 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.[16] The second line shows estimates

[14] See Appendix Table A1 for the list of LIS surveys per country that we use in our analysis.
[15] "when he/she last attended continuous full-time education", variable edcage in LIS.
[16] Our results also closely match those of Bowlus and Robinson (2012, Figure 3).

based on the annual CPS data for the 1991-2013, which corresponds to the period for which LIS data is available. The third line shows results based on LIS data for the 1991-2013 period.

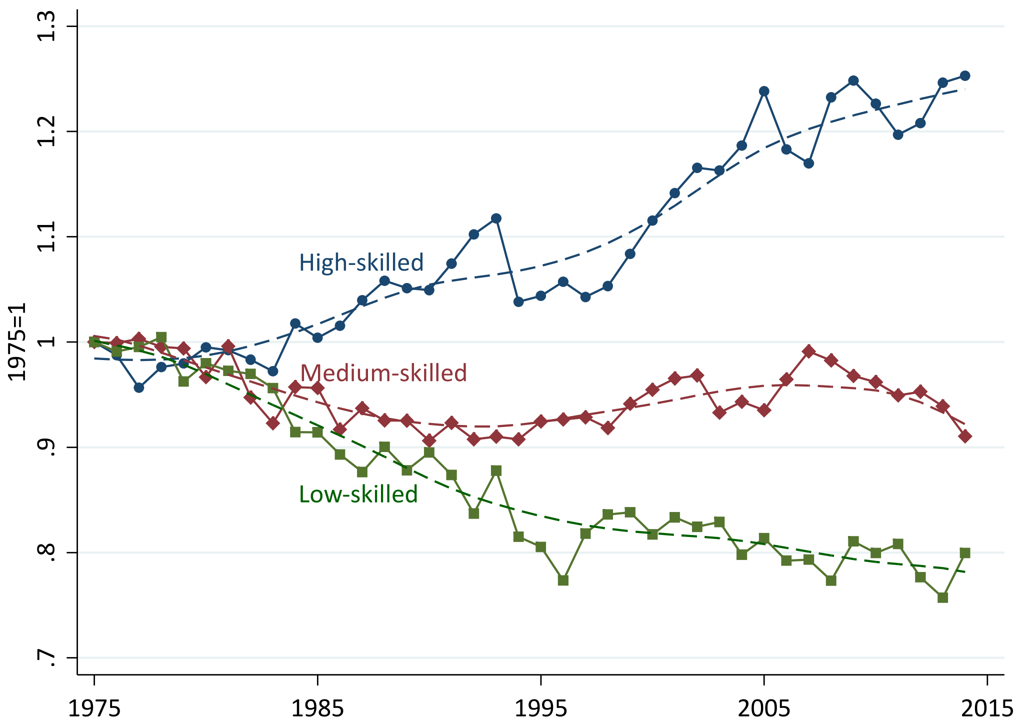
Table 3. The change in the price unit of labor services in the United States

		Change in the price per unit of labor services		
Country	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, 2016) and CPS data from IPUMS-CPS (Flood et al. 2015).
Note: 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.

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. In contrast, if wages are observed in year 1 and next in year 4, the price change is an average of 7 wage changes, 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) explicitly disregard relative price movements when analyzing changes in the quantity of labor services per hour worked, we will simply 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 1. 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 average 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.

Figure 1 shows the quantity of labor services per hour worked in the United States between 1975 and 2014, computed by dividing the average 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 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. The labor services per hour 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.

To establish that the patterns in Figure 1 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 these 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.

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: 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.

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 United Kingdom 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 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.[17] Due to variation in country coverage over time, we construct a 'Europe' series starting in 1994 and ending in 2013.

Table 5. The change in the price 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	0.23	-0.10	-0.21

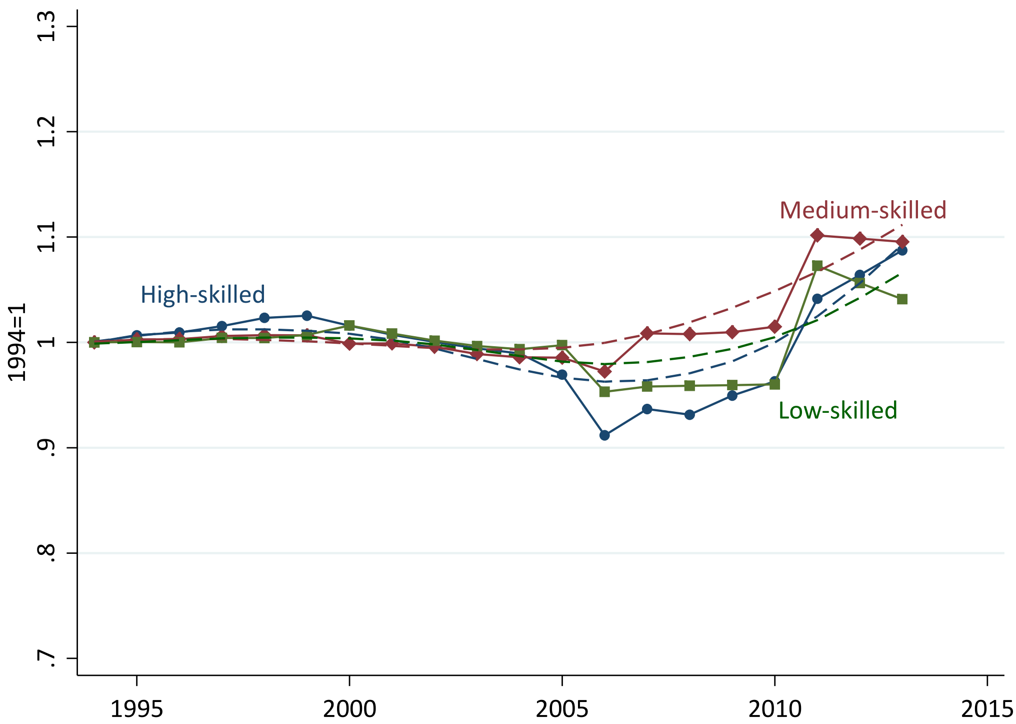
Source: Computations based on LIS data (LIS, 2016).
Note: The price per unit of labor services is computed based on equation (3) and the flat spot ranges in Table 2. Each entry in the table indicates the change in price over the stated period, relative to the change in the country's consumer price index.

Figure 2 shows the development of the quantity of labor services per hour worked for the six European countries, on the same scale as Figure 1 for the United States. 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. 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

[17] 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.

without fixed effects). 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 (cf. Table 4).

Figure 2. Labor services per hour worked in Europe, 1994-2013



Source: computations based on LIS data (LIS, 2016).
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 average 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.

Table 6. Linear time trend of labor services per hour worked in Europe, 1990-2013

	Low-skilled	Medium-skilled	High-skilled
Age 26-60	-0.0015*	0.0005	-0.0033
	(0.0007)	(0.0032)	(0.0037)
Age 26-35	-0.0052*	-0.0033	-0.0088*
	(0.0021)	(0.0038)	(0.0036)
Age 36-45	-0.0035**	-0.0013	-0.0032
	(0.0012)	(0.0028)	(0.0043)

Notes: 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.

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 1, 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,[18] the United Kingdom 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 worker. Before turning to the implications of the differences for high-skilled workers for measured productivity, we first assess the sensitivity of the results to the assumptions and choices we made.

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 1 and 2. Spain is not shown because its data series starts in 2007.

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

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

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 United States (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). The other two are computed using only wage information for workers within industry (manufacturing, construction) or only within services[19] 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 '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.[20]

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 United States and United Kingdom show increasing labor services per hour

[19] 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.

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

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.

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	0.25	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 7. 'US flat spot' uses the flat spot range for the United States 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.

Implications for Europe-US productivity growth comparisons

Our main finding is that labor services per hour worked of high-skilled workers in the United States and United Kingdom 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 United States. 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 United States and United Kingdom and underestimated in Continental European countries. Between 1995 and 2005, productivity growth in the United States 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.[21] In contrast, European countries showed notably lower productivity growth over this period, see also Table 9, 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:

$$\Delta \log A = \Delta \log V - \alpha \Delta \log K - (1-\alpha) \Delta \log L \quad (4),$$

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

[21] 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.

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:

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

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:

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

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):

$$\Delta \log A^* = \Delta \log V - \alpha \Delta \log K - (1-\alpha)\Delta \log L^* \ \ (4'),$$

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.[22] 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 of changes

[22] 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').

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

Table 9 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 hour worked shown under 'Standard growth accounting' and changes in total labor services under 'Adjusted for vintage effects'. So, for example, total hour worked of high-skilled workers grew at an average annual rate of 1.9 percent in the USA 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 vintages effects than based on standard growth accounting assumptions.[23] 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.

Table 9. 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. 2015); TFP growth from the EU KLEMS 2012 version (O'Mahony and Timmer, 2009).

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

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 7 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').

Under standard growth accounting assumptions, the United States 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 United States and United Kingdom is slower than in Germany, though still higher than in Italy and Spain. As recently argued by Gopinath et al. (2017) and Cette et al. (2016), 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.

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 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 United States (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 United States 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 United Kingdom, with even larger increases in labor services per hour worked by high-skilled workers over the same period. 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.

On one level, this is an encouraging result, because it provides a novel perspective on the Europe-US productivity growth difference and because the set of reasons for why productivity growth is high or low can be considerably larger than the set of reasons for why vintage effects were so different in the US and UK compared to the Continental European countries. At the same time, the Bowlus and Robinson (2012) methodology only pinpoints vintage effects but it does not provide an explanation for why they occur. It is also an open question to what extent the evidence for male workers can be generalized to female workers. We leave these important issues for future research.

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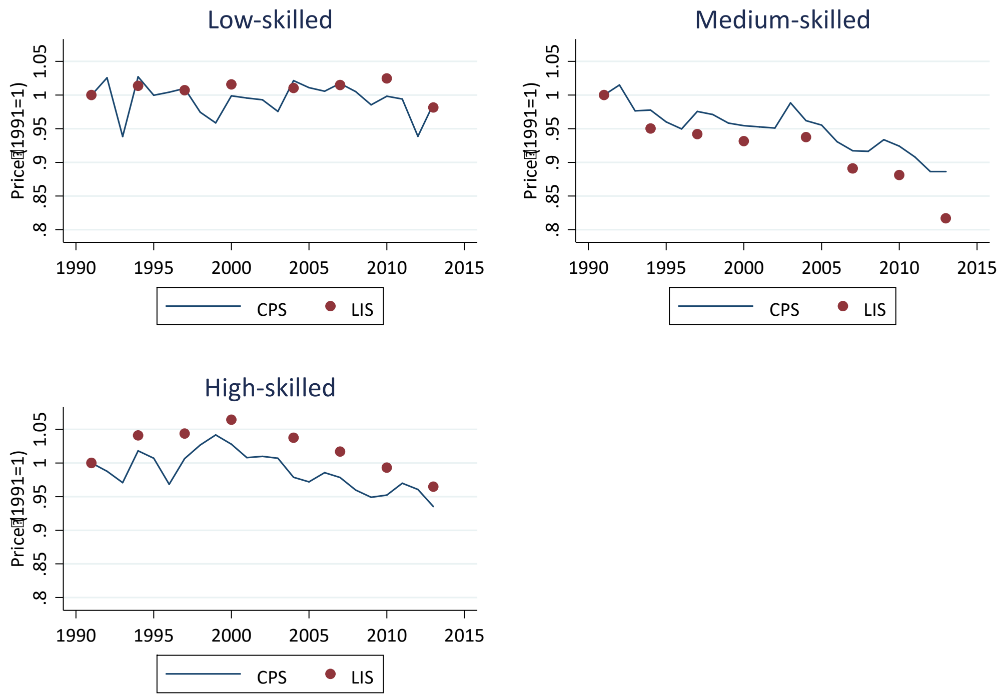
Appendix Figure A1. Price series for the United States based on CPS and LIS data for 1991-2013



Appendix Table A1. Coverage of LIS survey years

	LIS survey years covered
France	1994, 2000, 2005
Germany	1994, 2000, 2004, 2007, 2010, 2013
Italy	1991, 1993, 1995, 1998, 2000, 2004, 2008, 2010
Netherlands	1990, 1993, 1999, 2004, 2007, 2010, 2013
Spain	2007, 2010, 2013
United Kingdom	1994, 1999, 2004, 2007, 2010, 2013