Technology and Labor Regulations

Alberto Alesina

Harvard University CEPR and NBER

Joseph Zeira

The Hebrew University of Jerusalem, LUISS Guido Carli and CEPR

Revised: February 2009*

* We thank Daron Acemoglu, Olivier Blanchard, Francesco Caselli, Giovanni Di Bartolomeo, Giorgio di Giorgio, Gene Grossman, Sharon Haddad, Larry Katz, Francis Kramarz and Chris Pissarides for very useful comments. Filipe Campante and Sarit Weisbrod provided excellent research assistantship. Joseph Zeira thanks the Israel Science Foundation, the Aaron and Michael Chilewich Chair and the Mary Curie Transfer of Knowledge Fellowship of the European Community's 6th Framework Program under contract MTKD-CT-014288 for financial support. Remaining errors are of course ours only.

Abstract

Many low skilled jobs have been substituted away for machines in Europe, or eliminated, much more so than in the US, while technological progress at the “top”, i.e. at the high-tech sector, is faster in the US than in Europe. This paper suggests that the main difference between Europe and the US in this respect is their different labor market policies. European countries reduce wage flexibility and inequality through a host of labor market regulations, like binding minimum wage laws, permanent unemployment subsidies, firing costs, etc. Such policies create incentives to develop and adopt labor saving capital intensive technologies at the low end of the skill distribution. At the same time technical change in the US is more skill biased than in Europe, since American skilled wages are higher. In the last few years some partial labor market reforms in Europe may have started to slow down or even reverse this trend.

1. Introduction

It is close to impossible to find a parking attendant in Paris, Frankfurt or Milan, while in New York City they are common. When you arrive even in an average Hotel in an American city you are received by a platoon of bag carriers, door openers etc. In a similar hotel in Europe you often have to carry your bags on your own. These are not simply trivial traveler's pointers, but indicate a deeper and widespread phenomenon: low skilled jobs have been substituted away for machines in Europe, or eliminated, much more than in the US, while technological progress at the "top" i.e. at the high-tech sector, is faster in the US than in Europe. Why?

This paper suggests that an important difference between Europe and the US that leads to such technological differences lies is their different labor market policies. While US labor markets have been deregulated and labor unions there were significantly weakened, most European countries have kept wage inequality low through a host of labor market regulations, like binding minimum wage laws, permanent unemployment subsidies, firing costs, etc.[1] These European policies created incentives to develop and adopt labor saving capital-intensive technologies at the low end of the skill distribution. At the same time technical change in the US has been more skill biased than in Europe, since American skilled wages have been higher.

If we wish to model differences in technology adoption across countries, we need to assume that technology adoption is costly. One possibility is that such adoption costs are neutral with respect to factors of production, like in Parente and Prescott (1995). Such an assumption might help in understanding gaps between rich and poor countries, but it cannot explain sector differences in technology adoption. If adoption costs in Europe were higher, we should observe less technical progress in all sectors, which is not the case. We therefore assume instead that the costs of technology

[1] In the last few years there have been some reforms of labor markets in several European countries. How these will unfold remains to be seen, but job creation in Europe has immediately picked up in response to those changes. More on this below. See also Alesina and Giavazzi (2007) for discussion.

adoption are biased toward one of the factors of production, capital. More specifically, we follow the approach of Champernowne (1963) and Zeira (1998, 2007), who model technological change as substituting labor by machines. According to this approach new technologies reduce labor costs but require purchasing machines, namely increasing capital costs.[2] Hence, such technological innovations are invented and adopted only if wages are sufficiently high, so they reduce the cost of production.[3]

In this paper we apply this approach to a model of two sectors, skilled and unskilled, and we show that the wage in each sector determines the degree of technology in that sector. The model allows for two countries, which we identify as "the US" and as "Continental Western Europe" (Europe in short), to differ in their supplies of skilled and unskilled workers and in their labor market policies. Greater labor regulation in Europe, in the form of unemployment benefits, and/or minimum wage laws and/or firing costs leads to reduction in the skill premium in Europe, and as a result to less skill-biased technical change, but also to more technical progress in the unskilled sector, which even further raises the skill premium. We then calculate the welfare gains and losses from labor regulation, losses due to reduced output and gains due to social insurance.

Many economists have attributed the large rise in the skill premium in the US to skill biased technical change.[4] This paper suggests that both the rise of wage inequality and the skill biased technical change could have been to some extent a result of a third development, namely a deregulation in labor markets in the US. It therefore raises the hypothesis of some reverse causality,

---

[2] A different approach is taken by Basu and Weil (1998), who suggest that technology adoption depends on supplies of factors of productions, as different technologies fit better different capital-labor ratios. But this approach is less useful to analyze differences between skilled and unskilled sectors.

[3] The idea that a high cost of labor may lead to labor saving technologies is mentioned in other recent studies. Blanchard (1997) mentions substitution of labor by capital as one explanation for high European unemployment. Caballero and Hammur (1998) use a similar idea but do not apply it to low versus high skilled. Beaudry and Collard (2001) investigate convergence across industrial economies. Saint Paul (2006) studies the effect of technology on factor distribution. Acemoglu (2003) and Koeniger and Leonardi (2007) are discussed in detail below.

[4] See Davis and Haltwinger (1991), Katz and Murphy (1992), Bound and Johnson (1992), Juhn, Murphy, and Pierce (1993), Berman, Bound and Grilliches (1994), Greenwood and Yorukoglu (1997), Acemoglu (1998, 2003), and Berman, Bound and Machin (1998).

where the rise of wage inequality in the US induced skill biased technical change.[5] At the very least the technological revolutions in the US would have been seriously impeded if the labor market environment would have been more like in Europe, namely with stronger unions and with more regulation. Our model also implies that opposite policies in Europe led to wage compression and as a result to less skill biased technical change and more technical change in low skilled sectors.

Much recent research has examined the effect of the different labor market policies in the US and in Europe on the divergence between the two areas in economic performance after the 1970s. Higher unemployment in Europe relative to the US was attributed by many economists to these different labor market policies.[6] Unemployment has been just part of the story. The number of work hours per person has declined steadily in Europe (especially in France, Germany and Italy) since the 1970s relative to the US.[7] This paper adds to these economic outcomes also differences in technology.

Our paper is most closely related to two recent papers, Acemoglu (2003a) and Keoniger and Leonardi (2007). Acemoglu (2003a) shows that the differences in the skill premium between the US and Europe cannot be fully accounted to by the differences in labor supplies of skilled and unskilled workers in the two regions and not by the differences in labor market policies as well. He therefore concludes that there must be differences in technology between Europe and the US. Acemoglu then raises a hypothesis similar to us, that different labor market policies lead to differences in technology adoption, but he offers a very different mechanism than ours. His explanation is based on wage setting and its effect on investment through a hold-up mechanism and its elimination under minimum wage. Koeniger and Leonardi (2007) present a thorough comparison of the US and Germany until 1990.

---

[5] This possibility is also raised in Koeniger and Leonardi (2007).

[6] See Blau and Kahn (1996, 2002), Freeman and Katz (1995), Blanchard and Wolfers (2000) and recently Ljungqvist and Sargent (2006) among many who point at labor regulation and especially firing costs as the major explanation of recent European unemployment.

[7] This decline has been in part lower participation in the labor force, in part longer vacations, and in part shorter work weeks. See Prescott (2004) Blanchard (2004), Alesina Glaeser and Sacerdote (2005) and Rogerson (2007) for work on this point. More on this below.

They show that capital has been more complementary to unskilled workers in Germany than in the US and they also show, as Acemoglu does, that the standard neoclassical substitution of capital and labor cannot account for the full differences in capital intensity between the US and Germany. Our paper can therefore be viewed as supplying a theory of technology adoption that provides an alternative explanation to these differences between the two areas, which these two papers highlight.

Another literature which our paper is related to is that on 'induced innovations', which was pioneered by Kennedy (1964), Samuelson (1965), Nelson and Phelps (1966) and others. It has recently been connected to the endogenous growth literature by Acemoglu (1998), Acemoglu and Zilibotti (2001), Acemoglu (2003b) and others, in what is called 'directed technical change.' Our model and this literature have conflicting predictions on the relationship between relative wages and technical change. The reason for this difference lies in the different assumptions on the relation between technology and skill. In our model technical change both replaces skill and complements it, while in the directed technical change model capital only complements skill. This is why the two approaches have opposite predictions on technical progress and wages.

The paper is organized as follows. Section 2 presents the basic model, while Section 3 derives the basic results of the paper. Section 4 presents further results on the equilibrium and also a welfare analysis of the model. Section 5 contains more results and some extensions. Section 6 discusses some empirical implications of the model. Section 7 concludes and the appendix contains mathematical derivations of some results.

2. A Model of Technology and Labor Regulation

Consider a discrete time economy with overlapping generations. Each individual is born to a single parent, lives two periods and has a single offspring. Hence, population is fixed over time and we assume that each generation consists of a continuum of size 1. Individuals supply one unit of labor in first period of life and they can work as skilled if educated, or as unskilled if they are not. To an individual born to an educated parent learning is costless, but if born to an uneducated parent learning is infinitely costly. As a result the groups of skilled and unskilled are fixed over time.[8] Also assume that educated people can work as unskilled, while people without education cannot work as skilled.[9] Denote by L_n the share of unskilled and by L_s be the share of skilled, so that: $L_n + L_s = 1$. While skilled and unskilled differ in the sector they can work in, it is also assumed that all workers, skilled or unskilled, differ also by their individual efficiency e, which is assumed to be random, distributed uniformly between zero and 1, and independent of skill. There is a single final good in the economy, used for consumption and for investment. People derive utility from consumption of this final good in the two periods of life where $\rho > 0$:[10]

(1) $$\log(c_y) + \frac{\log(c_o)}{1+\rho}.$$

Note that the choice of an overlapping-generations assumption is not crucial for the main results of the paper, but is helpful. The main results could be derived in a model of infinitely lived individuals as well, but in that case we could not calculate the "ex-ante expected utility" because all individuals would have already known their efficiency level. Hence, it makes no sense in such a case to calculate the welfare gains of the insurance element in the labor market regulation. We could also present the analysis in a model of non-overlapping-generations, but in that case we would have only borrowers in our world and no lenders.

The single final good is produced by two intermediate goods, the skilled good S and the unskilled good N, using the following production function:

---

[8] This assumption can be relaxed to get mobility between skilled and unskilled. The main results of the model are not altered.

[9] This assumption only warrants that skilled wages are always higher or equal than unskilled wages.

[10] The log utility assumption has no effect on the results, as discussed below in Section 3.

(2) $$Y = S^{\alpha} N^{1-\alpha}.$$

The skilled good is produced by infinite tasks, or infinite intermediate goods $i \in [0,1]$ according to the following Cobb-Douglas production function:

(3) $$\log S = a + \int_0^1 \log s(i) di.$$

Each *i* can be produced by one of two potential technologies. One is manual, where a unit of *i* is produced by 1 efficiency unit of skilled labor. The second technology is industrial and it produces one unit of *i* by a machine of size or cost *k*(*i*). Capital, namely machines, depreciates fully within 1 period. Invention of a new technology, which is imbedded in a machine, is assumed for simplicity to be costless. This assumption has two implications. First, once producers are willing to adopt an industrial technology, it is invented and is available. Second, the only cost of the industrial technology for producers is the cost of the machine. It is assumed that this cost *k*(*i*) is rising with *i*.[11] To solve the model analytically we use the following specification:

(4) $$k(i) = \frac{1}{1-i}.$$

The unskilled good is produced by a similar production function:

(5) $$\log N = a + \int_0^1 \log n(i) di.$$

Similarly, each unskilled intermediate good can be produced either by one efficiency unit of unskilled labor or by a machine of size *k*(*i*), where the function *k* is the same as in (4).[12]

The economy is open to capital mobility and small, so that the world interest rate is given and equal to *r,* and the gross interest rate is *R* = 1 + *r*. The economy trades only in the final good, and not

---

[11] This is just an ordering assumption and has no effect on the analysis.
[12] We can assume that the sectors are not symmetric and that the cost of a machine that replaces a skilled worker is $b_s/(1-i)$, while the cost of a machine that replaces an unskilled workers is $b_n/(1-i)$. The qualitative results of the model remain the same.

in skilled, unskilled and intermediate goods. Note, that since our analysis focuses on international comparisons, the small open economy assumption is a very reasonable one. Still, the main idea of the paper holds in a closed economy setup as well, as shown in Section 4.2.

Finally we specify the labor market regulation and assume that workers without jobs are entitled to an unemployment compensation of v times the wage of a unit of efficiency of unskilled labor, where $v < 1$. This unemployment benefit is financed by a tax on income, at a fixed rate t. The tax is paid on the transfer payments as well and the government budget must be balanced.

3. Equilibrium with Endogenous Technologies

3.1. Technology Adoption

Denote by w_n (w_s) the gross wage rate per efficiency unit of an unskilled (skilled) worker. First, a skilled intermediate good is produced by machines, if:

$$w_s \geq Rk(i) = \frac{R}{1-i}.$$

Hence, all skilled intermediate goods $i \leq f_s$ are produced by machines, where the technological frontier for skilled workers, f_s, is determined by:

(6) $$1 - f_s = \frac{R}{w_s}.$$

Similarly: [13]

(7) $$1 - f_n = \frac{R}{w_n}.$$

[13] Note that (6) and (7) require that wages are greater than R. If not $f = 0$ and there is no industrialization. We do not dwell on this case as it is clearly remote from the advanced economies we analyze.

Hence, the low cost machines replace the workers in the corresponding jobs, while workers in the other jobs remain, as the machines that can replace them are too expensive. Note that although technical change substitutes labor by capital, it is also highly complementary to labor at the same time. Increasing f_s or f_n eliminates labor from some jobs, but makes the workers who crowd the remaining jobs, $[f_s, 1]$ or $[f_n, 1]$, more productive, since they work with more machines. For example, an accountant who uses a computer for calculations that she used to do manually in the past, becomes more productive as a result.

Let P_S be the price of the skilled good, and $p_s(i)$ be the price of the intermediate good i in the production of S. On the demand side we can use the first order conditions of profit maximization of producers of the final good, the skilled and the unskilled good. On the supply side prices of intermediate goods in the two sectors are equal to production costs, due to free entry and constant returns to scale. Hence:

(8) $$p_s(i) = \begin{cases} \dfrac{R}{1-i} & \text{if } \ i \le f_s \\ w_s & \text{if } \ i > f_s. \end{cases}$$

Prices of intermediate goods in the unskilled sector are similar. Equating demand and supply prices leads, as shown in the appendix, to the following equilibrium condition:

(9) $$\alpha f_s + (1-\alpha) f_n = a + \varepsilon - \log R,$$

where $\varepsilon = \alpha \log \alpha + (1-\alpha)\log(1-\alpha)$. We call equation (9) the "goods markets equilibrium condition." It describes a trade-off between the two technology frontiers.

Denote the wage ratio between the skilled and unskilled by I, as it reflects the degree of wage inequality in the economy. From conditions (6) and (7) we get that this wage inequality is related to the technology frontiers in the two sectors:

$$I = \frac{w_s}{w_n} = \frac{\dfrac{R}{1-f_s}}{\dfrac{R}{1-f_n}} = \frac{1-f_n}{1-f_s}.$$

Hence, we get the "labor market constraint:"

(10) $$f_n = 1 - I + If_s.$$

Together, equations (9) and (10) determine the equilibrium values of technologies adopted and the wages in each sector given the wage ratio *I*, as shown in Figure 1.. The **G** curve describes the goods market equilibrium condition (9), while the **L** curve describes the labor market constraint (10). Since skilled workers can always switch and work as unskilled the wage ratio *I* satisfies: $1 \le I < \infty$.

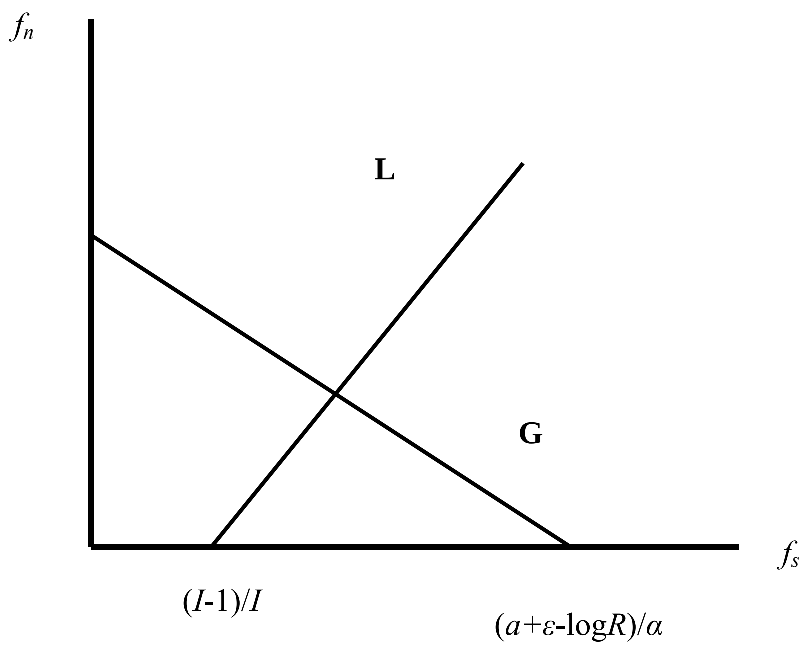


Figure 1: Determination of Technology Frontiers

A calculation of the equilibrium shown in Figure 1 yields the two technology frontiers:

(11) $$f_s = 1 - \frac{1 + \log R - \varepsilon - a}{\alpha + (1-\alpha)I},$$

and:

$$(12) \qquad f_n = 1 - I\frac{1+\log R-\varepsilon-a}{\alpha+(1-\alpha)I}.$$

A sufficient condition for no corner solution at any wage inequality *I* between 1 and infinity is that the basic productivity parameter *a* should satisfy:

$$(13) \qquad \alpha + \log R - \varepsilon \le a \le 1 + \log R - \varepsilon.$$

As wage inequality *I* increases, the curve **L** shifts down, reducing f_n and increasing f_s. . Hence wage inequality induces technical adoption of machines in the skilled sector but reduces it in the unskilled sector. As a result, the wage of skilled workers rises and the wage of unskilled workers declines. A change in productivity *a*. instead shifts the curve **G**. Hence, a country with higher productivity adopts more technologies in both sectors, skilled and unskilled.

As shown above reducing wage inequality raises the wage of unskilled, but also lowers the wage of skilled. The reason is the complementarity between the skilled and unskilled goods in the production of final goods (2). Raising wages of unskilled reduces their input and thus reduces the unskilled good. This lowers the marginal productivity of the skilled good, its price and the skilled wage as well. Thus, policies that raise the unskilled wage in order to reduce wage inequality end up in lowering the wages of the skilled as well.

3.2. Equilibrium Wage Inequality

A worker chooses to work only if her earnings exceed the welfare payment. Hence an unskilled works only if: $ew_n(1-t) \ge vw_n(1-t)$, namely if $e \ge v$. The unskilled rate of unemployment is therefore

$$(14) \qquad u_n = v.$$

A skilled supplies labor if: $ew_s(1-t) \ge vw_n(1-t).$ Hence:

$$(15) \qquad u_s = \frac{v}{I}.$$

Note that this is voluntary unemployment. Involuntary unemployment is described in Section 4 and the Appendix when we discuss minimum wages and firing costs.

We next derive the wage ratio I from the labor market equilibrium conditions for skilled and unskilled. The appendix shows how these conditions are derived from equating supplies and demands for labor in terms of efficiency units of skilled labor:

$$\frac{L_s}{2}\left(1-\frac{v^2}{I^2}\right)=\frac{\alpha RY}{w_s^2}, \tag{16}$$

and of unskilled labor:

$$\frac{L_n}{2}\left(1-v^2\right)=\frac{(1-\alpha)RY}{w_n^2}. \tag{17}$$

From these two conditions we derive the equilibrium value of wage inequality I:

$$I^2=\frac{\alpha}{1-\alpha}\frac{L_n}{L_s}(1-v^2)+v^2. \tag{18}$$

We next note that the following condition always holds:

$$\alpha L_n/[L_s(1-\alpha)]\geq 1. \tag{19}$$

This is a result of the assumption that skilled workers can always work in the unskilled sector. If this condition does not hold, the wage ratio is lower than 1 and as a result skilled workers turn to unskilled jobs, which pay a higher wage. That drives wage inequality up to 1, by reducing the actual L_s and increasing L_n, which restores this condition. Thus, condition (19) implies that wage inequality is greater or equal to 1, and also that it depends negatively on the degree of labor market regulation v.

3.3. The Effect of Unemployment Compensation

A country with a larger unemployment compensation v has a lower wage inequality I. As a result this country adopts less machines in the skilled sector, namely f_s is lower, but has more machines in the unskilled sector, namely f_n is higher. In such a country w_s is lower and w_n is higher. The effect of labor regulation on wage inequality works through the effective supplies of skilled and unskilled labor since unemployment compensation reduces the supply of unskilled by more than the supply of skilled.

Note, that the effect of labor regulation v on wage inequality *I* is amplified by technology choice. A decline in *I* due to labor regulation reduces technology in the skilled sector and increases it in the unskilled sector. This further lowers the skilled wage $R/(1-f_s)$ and further raises the unskilled wage $R/(1-f_n)$. Hence, the skill premium in this economy rises not only as a result of reduced regulation, but also as a result of the interaction with technology adoption. This amplification is manifested in the square of wage inequality in equation (18).[14]

4. Output and Welfare

In this section we further describe the equilibrium, by calculating the levels of aggregate output, the tax rate and welfare. We also try in this section to examine why countries differ in their labor regulation, namely in *v*.

4.1. Output and Government Budget

The aggregate unemployment rate is:

$$u = L_n v + L_s \frac{v}{I} = v\left[1 - L_s\left(1 - \frac{1}{I}\right)\right].$$

Aggregate output is calculated from the labor market equilibrium (16) and is equal to:

(20) $$Y = \frac{L_s}{2\alpha R}\left(1 - \frac{v^2}{I^2}\right)w_s^2.$$

An increase in *v* reduces *I* and reduces w_s. Hence, labor market regulation *v* reduces output and increases unemployment. The balanced budget requires that taxes equal unemployment benefits:

[14] This amplification effect has been noticed by Koeniger and Leonardi (2007).

(21) $$tY = (L_n u_n + L_s u_s) v w_n = (L_n v + L_s v / I) v w_n .$$

If v is higher, both the unemployment rate is higher and the compensation per unemployed is higher, so that the overall amount of compensation, the right hand side of (21), is higher. Since output or income is lower, the tax rate must be higher as well.

4.2. Welfare Considerations

As shown above, labor regulation reduces output and increases the tax rate. Is it possible that it is still increases welfare, as it creates insurance against low efficiency? This issue is discussed in this sub-section. We examine the ex-ante expected utility of each person at birth, before her efficiency is revealed, as the correct measure of welfare. This is actually the average utility of skilled and of unskilled in each generation. In the appendix we show that ex-post utility is a linear transformation of the logarithm of net income. We therefore use log income as a measure of indirect utility. As shown in the appendix expected utility of unskilled is equal to:

(22) $$U_n = \log w_n + v + \log(1-t) - 1,$$

and expected utility of skilled is equal to:

(23) $$U_s = \log w_s + \frac{v}{I} + \log(1-t) - 1.$$

The effect of increasing v is therefore mixed. On the one hand it has a direct positive effect on welfare, due to reducing the probability of poverty and low income. On the other hand it raises tax payments. Also, increasing welfare raises the unskilled wage, but lowers skilled wage. Hence it has different effects on the two types of workers.

The average welfare within a generation is a reasonable measure for ex-ante welfare, since the government does not transfer income across generations. The average ex-ante expected welfare, with equal weights to all, is equal to:

(24) $$\text{AVG}(U) = L_n U_n + L_s U_s = (1 - L_s) U_n + L_s U_s .$$

In the rest of the sub-section we focus on this variable in order to find, which level of labor regulation v maximizes average welfare. We then examine whether the difference in labor regulation between Europe and the US can be explained by our model. Since the two countries differ in L_s, they might differ also in their optimal v. Can that explain the observed difference in labor regulation and the resulting difference in wage inequality between the two regions?

The analytical calculation of average utility is quite complicated, so we resort to simulations. For that, we must specify reasonable values for the four parameters of the model: productivity a, the gross interest rate R, the share of skilled goods in the production of the final good α, which is also the elasticity of the final good with respect to the skilled good, and the share of skilled workers in the population L_s.

Our choice of parameters is guided by our interest in comparing the US and Europe. Assuming that they are similar in interest rates and production parameters, we compare outcomes across different values of L_s, keeping the other parameters equal. For values of L_s we choose the percentage of the population between ages 15 and 64 that had completed tertiary education in 1995, taken from Barro and Lee (2001). Thus for the US $L_s = 0.33$, and for Europe $L_s = 0.17$, where "Europe" is taken to be the average of France, Germany, and Italy.[15] R =2 is a realistic interest rate for a period of one generation. To set α note that the ratio of wages of college graduates and of high school graduates in the US has been 1.9 in the late 1990s, as shown by Autor, Katz, and Kearney (2005). We then apply this figure to equation (18) and find that if v is somewhere between 0 and .5 (which is a reasonable range for the US, as it has high participation rate in the labor force) α should be between .64 and .69. We therefore set α

[15] A word of caution is required. Many skilled jobs in Europe are performed by graduates of high schools and especially technical high schools. Also, there are differences between hours worked between the US and Europe that might change the ratios of skilled to unskilled as well. But we use the figures from Barro and Lee (2001) as a first approximation. As the figure below shows such differences don't matter so much.

= 2/3 as an intermediate value. Finally, the productivity parameter a is set to satisfy condition (13) for an interior solution: $1.99 \leq a \leq 2.33$. We therefore set a = log(8) ~ 2.08.

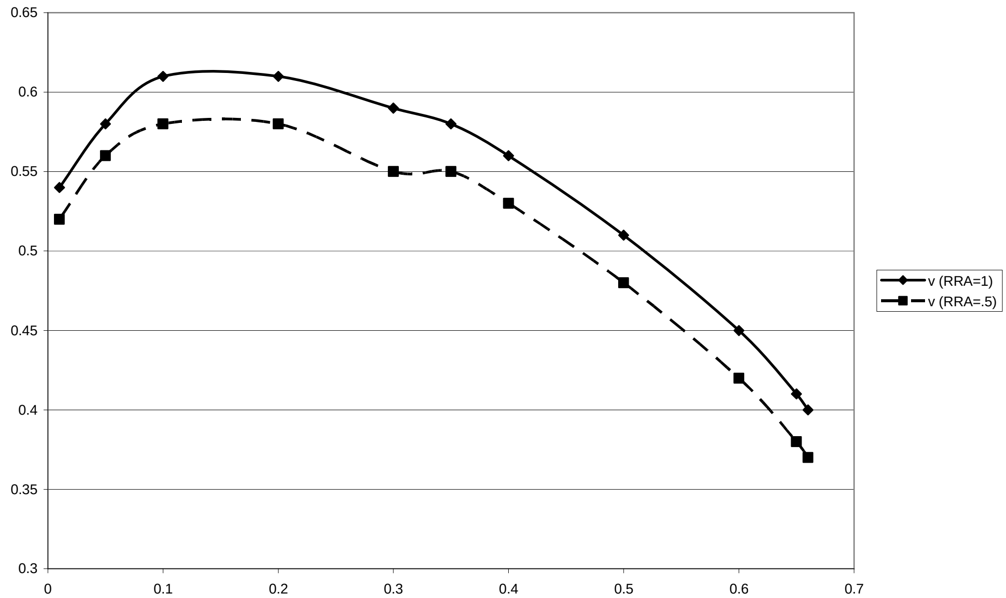


Figure 2: Optimal Unemployment Compensation

Figure 2 shows how the level of v that maximizes AVG (U), changes with the amount of skill. Figure 2 is drawn for $L_s \leq 2/3$, as implied by the constraint $\alpha L_n / (1-\alpha) L_s \geq 1$, which is required by $I \geq 1$. Figure 2 is drawn both for the logarithmic utility function used in the benchmark model, with relative risk aversion of 1, but also for a much lower level of risk aversion of .5. Figure 2 shows that optimal v is positive, namely labor market regulation increases welfare by supplying insurance against being born with low efficiency.[16] Figure 2 also shows that optimal v does not change much with the share of skilled in the population. Optimal v fluctuates between .4 and .61 and actually, due to

[16] We can also consider a Pareto-dominating policy, of means tested transfer payment. But such a policy fails if efficiency is not observed when the worker does not work. Then workers with low efficiency prefer to avoid work altogether. Under such moral hazard the policy in the model is indeed optimal.

concavity, in most of the relevant range it fluctuates between .52 and .61. Figure 2 also shows that optimal v does not depend much on the degree of risk aversion.

The locations of US and Europe on the curve in Figure 2 point at their optimal unemployment compensation. We can use equation (18) to calculate their implied v, namely the unemployment compensation which yields the observed wage inequality in the country, according to the model. The optimal v for the US should be .58. Its implied v, for a wage ratio of 1.9, is .383. The optimal v for Europe should be .61. Since the wage ratio in Europe is 1.4 according to Brunello, Comi, and Lucifora (2000), its implied v is .943.[17] This simple exercise implies that unemployment compensation in the US is significantly below the optimal while in Europe it is significantly above the optimal. This means that our model cannot explain the differences in labor regulation, or social policies, between the US and Europe. Namely, the different supplies of skill are not the only source of difference between Europe and the US. There are also other explanations, including different degrees of aversion to inequality and different perception of the benefits of social insurance versus market distortions.[18]

5. Further Results and Some Extensions

5.1. The Aggregate Production Function

In this sub-section we present the aggregate production function of the economy in an explicit way to provide an alternative view of the production possibilities and of the issue of technology choice in this model. Assume that there is an aggregate amount of capital of K in the economy, and that the supplies of skilled and unskilled labor, in terms of efficiency units, are L_s^e and L_n^e, respectively. As shown in the Appendix, the maximum amount of output that can be produced with these inputs is equal to:

[17] This is of course a very high and unrealistic figure, but it points to the conclusion that intervention in Europe is very high relative to the US.
[18] See Alesina and Glaeser (2004) for more discussion of this point.

(25) $$Y = \exp[a + \varphi(f_s, f_n)] K^{\alpha f_s + (1-\alpha) f_n} L_s^{e\,\alpha(1-f_s)} L_n^{e\,(1-\alpha)(1-f_n)},$$

where φ is a function of the technology frontiers f_s and f_n, which is specified in the appendix. This is therefore a Cobb-Douglas production function in the three factors of production: capital, skilled labor and unskilled labor. Unlike other Cobb-Douglas functions, the shares of the three factors of production are not constant but depend on the technology frontiers. Hence, in this production function changes in aggregate inputs affect output by more than their marginal productivities, since they induce changes in technology levels and thus further change output.

According to (25) the optimal levels of technology, f_s and f_n, are chosen to maximize output, as shown in the appendix. Intuitively, the main result of the model already follows from (25). If the supply of skilled labor is higher, fewer technologies are adopted and f_s is lower. A similar result applies to technology in the unskilled sector f_n. Hence, a lower wage gap, which is related to more skilled relative to unskilled labor, leads to unskilled biased technical change.

5.2. Capital across Sectors

Next we calculate the equilibrium amounts of capital in each sector. Capital in the skilled sector is:

(26) $$K_s = \int_0^{f_s} \frac{s(i)}{1-i} di = f_s \frac{P_S S}{R} = \alpha f_s \frac{Y}{R}.$$

Capital in the unskilled sector is:

(27) $$K_n = \int_0^{f_n} \frac{n(i)}{1-i} di = f_n \frac{P_N N}{R} = (1-\alpha) f_n \frac{Y}{R}.$$

If wage inequality declines, due to greater unemployment compensation, capital in the skilled sector K_s is reduced relative to output, while K_n increases relative to output. This is an empirical implication that we examine below in Section 6. Note also that the positive relationship between wage inequality and the relative capital in the skilled sector is observationally equivalent to capital-skill complementarity.[19]

5.3. Other Forms of Labor Regulation

Unemployment compensation is not the only form of labor market regulation. Amongst the most common other regulations are binding minimum wage floors, and various costs and legal prohibitions of firing workers. In our model these policies yield qualitatively the same results as unemployment compensation, namely they reduce wage inequality, raise unskilled wages, lower skilled wage and thus bias technology toward the unskilled sector.

To study the effect of minimum wages we apply such a policy to our basic model from Section 2. Only one assumption needs to be changed, which is the assumption that worker's efficiency is known to all. Under this assumption all workers with efficiency below the minimum wage are fired. It means that the minimum wage policy hurts all and thus no one should want it. We assume instead that worker's efficiency is unknown but can be observed by employers for only some of the workers. Hence, only part of the workers who have low efficiency, are fired. The appendix shows that in this model a minimum wage regulation reduces wage inequality, since it applies mostly to unskilled. Therefore, the minimum wage regulation induces unskilled bias technology and reduces skill-bias technologies.

The appendix also contains an analysis of the effect of firing costs on wages and technology. It shows that firing costs have a similar effect to that of unemployment benefits or minimum wages. The intuitive reason is that prices of intermediate goods reflect also firing costs and these are relatively larger for unskilled. Thus firing costs reduce the ratio of prices (and wages) between the two sectors. Note that both under minimum wages and under firing costs some workers become involuntarily

---

[19] Note that the aggregate capital output ratio is equal to $[a+\varepsilon\text{-}\log R]/R$, as shown by equations (19), (20) and (9). Hence, the aggregate capital output ratio is equal across countries. It differs only with respect to sectors.

unemployed. Hence, such policies should usually be accompanied with some welfare payments, or unemployment benefits. In these cases it does not affect the equilibrium if the amount of unemployment benefits is lower than the minimum wage.

All these labor regulations reduce wage inequality. This is also often a direct objective of labor unions and of governments, especially in Europe.[20] Such policies yield similar results to those described above, since setting a bound on wage inequality is equivalent to minimum wages. Another way to understand this issue is to consider a union that acts as a labor monopoly and sets higher unskilled wages. All these deviations from competitive wage inequality lead to the same result with respect to the adoption and creation of technologies. They discourage technologies in the high skilled sectors and encourage more technologies in the unskilled sector.

6. Some Empirical Evidence

In this section we review some empirical evidence that supports the implications of our model. Part of it is gathered from works by others and part is added by us. The evidence is drawn mostly from comparisons between the US and Continental Western Europe (Europe in short).

6.1. Labor Market Regulation and Wage Compression

Up to the mid-seventies unemployment was lower in Europe than in the US and Europeans were working longer hours. Then that everything changed: unemployment increased and remained much higher in Europe than in the US and hours worked per person fell in Europe while they remained roughly constant in the US. What happened? The supply shocks of the seventies were accompanied by wage moderation in the US, while in Europe strong unions imposed real wage growth. At the same time European governments continued with the policies that began in the late sixties, of introducing

[20] For a discussion of Europeans' aversion to inequality and unions' policoes to limit wage inequality see Alesina and Glaeser (2004), Alesina, Di Tella and Mc Culloch (2004), Blau and Khan (2002) and also Kramarz (2007).

and then reinforcing a host of labor market regulations such as binding minimum wage laws, firing costs and unemployment subsidies often unrelated to job search.[21] As convincingly shown by Blanchard and Wolfers (2000), amongst others the interaction of this kind of labor institutions and those macroeconomic shocks generated persistent unemployment. Alesina, Glaeser and Sacerdote (2005) also discuss how union policies led to reduction of working hours for those who remained at work.[22] Rogerson (2007) offers two additional explanations to the reduction of working hours, one is higher taxation [as in Prescott (2006)]and the other is difference in technology, as Europe specializes much less in services than the US. These explanations fit nicely within our approach, since we claim that different regulation and taxation also lead to differences in technology adoption. Rogerson and Wallenius (2007) find that the difference in employment between the two sides of the Atlantic is concentrated on elderly and young entrants. In the case of the latter, firms were traditionally reluctant to hire workers that had low skills and needed to be trained on the job[23]

In the eighties and the nineties Europe and the US diverged also in their wage gaps between skilled and unskilled.[24] As Blau and Khan (1996, 2002) document, the ratio of wages in the 50-10 deciles increased in those years in the US by 13 per cent for men and by 18.6 per cent for women. In Europe this ratio increased only by 4 and 3 per cent respectively. In their study Blau and Kahn (2002) conclude, after controlling for many other factors and variables, that union policies and labor market

[21] See Lazear (1990) and the detailed study of French labor institutions by Blanchard, Cohen and Nuveau (2005).

[22] Alesina Glaeser and Sacerdote (2005) calculate that about one third of difference in work hours per person between France and Germany on one side and the US on the other is due to higher participation in the labor force in the US. Comparing US and Italy the same factors (labor force participation) explain more than half of the difference in work hours. Additional factors explaining lower work hours are marginal tax rates (Prescott (2004)) and preferences for leisure (Blanchard (2004)).

[23] The effect on the elderly has to do with incentives to retire and the generosity of pension systems.

[24] See Katz and Murphy (1992) for early work on relative supply of skilled versus unskilled labor.

regulations were crucial in explaining the difference in wage dispersion on the two sides of the Atlantic.[25]

6.2. Differences in Capital Intensity

In this sub-section we present some observations that support our claim that there are difference in technology between the US and Europe along the skill line, and that these differences are reflected in differences in capital intensities.

6.2.1. Capital Labor Ratios

Blanchard (1997) notes that after the shocks of the seventies European firms shifted to labor saving technologies, which increased the capital labor ratio and after a period of adjustment, also raised profits. From 1980 to the late nineties capital-labor ratios have been increasing steadily and sharply in Continental Europe, while they have been quite stable in Anglo-Saxon economies, as shown in Figure 3. Caballero and Hammur (1998) report a positive correlation between the capital labor ratio and the degree of labor protection in OECD countries.

This evidence does not distinguish between low killed and high skilled sectors. In order to make progress we turn to the European Union report edited by O'Mahoney and van Ark (2003), which compares productivity between Europe and the US, with data from the OECD and the Groningen Growth and Development Center. The study shows indeed that productivity and capital intensity vary by sector across the two regions. This study compares the levels of capital per hour worked at 2000, relative to total economy ratios, between the US and four European countries: France, Germany, Netherlands, and UK. The report divides sectors to four levels of skill: high, high intermediate, low intermediate and low. Taking only the high and low skill sectors and avoiding the public sectors we summarize the comparison in Figure 4.[26] Clearly all high-skill sectors in the US use relatively more

[25] See also Gottschalk and Smeeding (1997) for a discussion of wage dispersion in OECD countries.
[26] This figure is based on Tables II.6 and II.9a in O'Mahoney and van Ark (2003).

capital per labor than in Europe. On the contrary, most low-skill sectors in Europe use more capital per labor than in the US, except for Agriculture and mining. Note that these two sectors are also geography dependent. Since the US is land abundant relative to the major European countries this can explain the high capital to labor ratio in these sectors. In general, these results support the main claim of our theory.[27]

6.2.2. Capital Output Ratios

Remember that from equations (26) and (27) we get that this ratio in the skilled sector is

$$\frac{K_s}{Y} = f_s \frac{\alpha}{R}.$$

and in the unskilled sector it is

$$\frac{K_n}{Y} = f_n \frac{1-\alpha}{R}.$$

Hence, comparing capital output ratios across countries enables to compare the degrees of skill-biased and unskilled-biased technologies. A word of caution; Capital usually includes not only machines and equipment, which are the focus of our model, but also structures, which could differ across countries due to many reasons, like land abundance.

With this in mind we have assembled data on capital in the skilled and unskilled sectors in the US and in Europe with special emphasis on the three largest Continental European countries: Germany, France and Italy. The data for the European countries are from the OECD, while the data for the US is from the BEA, as the OECD Stan data do not include these data for the US.[28] We divided (in a rough manner) sectors between skilled and unskilled according to the share of skilled professions,

[27] This also conforms with Koeniger and Leonardi (2007), who say: “the capital-labor ratio has increased more in Germany than in the US in the period 1975-1991, especially in the unskilled labor intensive sectors.”

[28] The two data sets differ in their sector qualification, as the BEA data follow NICS while the OECD data follow SICS. We have matched the two data sets together.

where a sector with more than 50% skilled is defined as skilled.[29] We then sum up net capital stocks in both types of sectors to get K_s and K_n.

Figure 5 presents the ratios of capital to output in the skilled sectors in our four countries: US, France, Germany, and Italy. It shows that the level of technology in these sectors was higher in the US than in the European countries, except for Germany. Figure 6 shows the ratios of capital to output in the unskilled sectors and it clearly shows that unskilled biased technology in the US is below the European countries in recent decades. Furthermore, the two figures show that while skill-biased technology increased in the US in recent decades, unskilled-biased technology declined significantly at the same time.

Dividing all sectors to low and high skilled may be problematic, due to the many intermediate sectors, so it may be useful to look at more specific sectors, mainly at those where the definition is more likely to be accurate. When dealing with specific sectors, which are relatively small we look at the ratio of capital to value added at the sector rather than country output *Y*, to control for differences in relative size of sector. Note that from equations (19) and (20) we get that the ratios of capital to value added in the two sectors are $K_s / P_S S = f_s / R$ and $K_n / P_N N = f_n / R$. Hence, these ratios provide good signals to the state of technology in a sector.

We focus first on two sectors, which are very low skilled, according to all sources: textile and other community, social and personal services.[30] Figure 7 shows that the ratio of capital to value added in these sectors is higher in continental Europe than in the US. The same results apply if we focus only on the three largest economies France, Germany and Italy. On the other end of the skill ladder are

[29] The classification of sectors to skilled and unskilled is done by BLS data for 1989 and 1990.
[30] See O'Mahoney and Van Ark (2003) for various sources to the skill taxonomy.

the computer sector and the education sector, which are clearly high skilled. They indeed have higher capital to value added ratio in the US relative to continental Europe, as displayed in Figure 8.[31]

The two biggest sectors that are more intermediate but are still classified by O'Mahoney and Van Ark (2003) as LIS (less intermediate skilled), are construction and the retail and wholesale sectors (where retail has lower skills than wholesale). Figure 9 shows that the capital to value added ratio in retail is indeed higher in Europe than in the US. Glyn et al. (2007) examine in detail the service sectors in the US and in Europe and show that the capital labor ratio in retail relative to the capital labor ratio in manifactirung was 0.34 in the US, 0.43 in France and 0.56 in Germany. Thus, the low skilled retail sector is relatively more capital intensive in france and germany than in the US.[32] The same authors find that "in the US…in retail the least skilled are overrepresented while in France and Germany they are underrepresented." They also show that in the eighties and nineties these divergent trends have been especially striking between France and the US.

6.3 Innovations

We next look at some direct evidence on technology adoption. Comin and Hobijn's (2004) data set contains information on adoption of some technologies by 24 countries over the last 215 years. We compare US to France, Germany and Italy, the three largest Continental European countries. For most of the technologies in the data set it is unclear whether they are low skill or high skill labor saving, but for two cases we feel pretty confident. Figures 10 and 11 show the patterns of adoption of personal computers and of industrial robots in these countries. One could safely argue that computers substitute (and complement) high skill labor while robots substitute for low skill labor. The figures show that there are significantly more PCs per capita in the US than in the three European countries while there are significantly more robots per capita in the three European countries.

[31] We should caution that since most education is public it might not always react to market prices. Figure 7 implies that it does with respect to input prices.
[32] See table 6 of Glyn et al (2007).

Finally, additional evidence consistent with our theory is presented in Lewis (2005). Using plant level data, he shows that the degree of adoption of automation technologies (thus of capital intensity) is higher in US cities that have received less immigration of low skill workers. He even uncovers de-adoption of automation technologies in cities that receive an especially large influx of low-skill immigrants.

6.4. Job Creation

One implication of our argument is that the ratio of high skilled jobs created in Europe relative to low skilled jobs should be higher than in the US. Pissarides (2006) indeed finds that until very recently job creation in Europe was sluggish in the low-skilled service sectors, where most job creation has occurred in the US and UK.[33] Pissarides (2006) concludes that European countries in the nineties have been successful at creating jobs in the "knowledge sectors" …but unsuccessful at creating them in "labor intensive….sectors," which is exactly one of the implications of our model.[34] His paper also shows a strong negative correlation between the level of labor market regulations and job creation in low skilled community service jobs (Figure 6 of Pissarides (2006)).

In recent years a few continental European countries such as France and especially Italy and Spain have introduced entry level temporary labor contracts outside of the tightly regulated primary market. The results have been immediate: in the last few years job creation has jumped up, especially in Spain and Italy, for jobs using these types of contracts. Boeri and Garibaldi (2007) document in detail how after the partial labor market reforms of the late nineties that introduced temporary contracts available to employers outside of the tightly regulated primary market, employment in these countries increased dramatically, despite a relative low GDP growth. Europe went from jobless growth to job creation with low growth. In table 1 of their paper Boeri and Garibaldi (2007) document

[33] See also Rogerson (2007) for a discussion of the sluggish growth of the service sector in Europe versus the Us and its effects on hours worked.
[34] See Table 4 of Pissarides (2006) for evidence.

how the rapid growth of employment since these labor reforms in six continental European countries was almost exclusively driven by temporary contracts and not in the primary labor market. Since the late nineties Spain created 3 million of these types of jobs, about 30 per cent of the labor force. Call centers and a variety of others low skilled occupations have started to appear very recently in Continental Europe as well.

7. Conclusions

After the seventies' the performance of labor markets in Europe and in the US departed significantly in many aspects. In the US labor markets further deregulated and the US experienced a sharp increase in wage inequality, a stagnation of real wages for low skilled work, low unemployment and stability of hours worked per person. In Europe, on the contrary, labor regulation increased in the aftermath of the early seventies' shocks. Unions' policies targeted defending wages by imposing binding minimum wage laws and similar regulations. The result has been higher and persistent unemployment, lower hours worked per person and a much more equal wage distribution.

This paper shows how these developments in relative wages also influenced technology adoption in the two places. Lower wage gaps in Europe have led firms to switch to labor saving technologies at the low end of the skill distribution. Hence, low skilled labor has been substituted away by machines in Europe more than in the US. Meanwhile, opposite development occurred at the US, where higher skilled wages encouraged skill biased technical change much more than in Europe. Obviously various exogenous developments in science and technology, like the invention of computers, have played an important role as well, but we claim that the speed of adoption and of adjustment to new technologies depends on labor market regulations and policies.

Appendix

Derivation of the Goods Market Equilibrium Condition

The first order condition for each intermediate good in the skilled sector is:

(A1) $$p_s(i) = P_S \frac{\partial S}{\partial s(i)} = \frac{P_S S}{s(i)}.$$

Equating this demand price with the supply price in equation (8), deriving *s*(*i*) and then substituting in the production function of the skilled good (3) we get:

$$\log S = a + \int_0^1 \log \frac{P_S S}{p_s(i)} di = a + \log S + \log P_S - \int_0^{f_s} \log \frac{R}{1-i} di - \int_{f_s}^1 \log w_s di =$$

$$= a + \log S + \log P_S - f_s \log R - (1-f_s)\log w_s + \int_0^{f_s} \log(1-i)di.$$

Due to (6) and $\int_0^{f_s} \log(1-i)di = -(1-f_s)\log(1-f_s) - f_s$ the price of the skilled good is equal to:

(A2) $$\log P_S = f_s + \log R - a.$$

In a similar way it is shown that the price of the unskilled good is

(A3) $$\log P_N = f_n + \log R - a.$$

While these prices reflect the supply side, from the demand side prices satisfy the following first order conditions:

$$P_S = \frac{\partial Y}{\partial S} = \alpha S^{\alpha-1} N^{1-\alpha} = \frac{\alpha Y}{S},$$

$$P_N = \frac{\partial Y}{\partial N} = (1-\alpha) S^{\alpha} N^{\alpha} = \frac{(1-\alpha)Y}{N}.$$

Substituting these first order conditions into the production function (2) we get the following constraint on the prices of the two goods:

(A4) $$\alpha \log P_S + (1-\alpha)\log P_N = \varepsilon,$$

where ε denotes $\alpha \log \alpha + (1-\alpha)\log(1-\alpha)$. Substitute (A2) and (A3) in (A4) and get:

$$\alpha f_s + (1-\alpha) f_n = a + \varepsilon - \log R.$$

This is the goods markets equilibrium condition.

Derivation of the Labor Market Equilibrium Conditions

The supply of employed skilled labor in efficiency units is equal according to (15) to:

$$\frac{L_s}{2}\left(1-\frac{v^2}{I^2}\right).$$

The supply of unskilled labor is equal according to (14) to:

$$\frac{L_n}{2}\left(1-v^2\right).$$

The demand for skilled labor is equal to:

$$\int_{f_s}^{1} s(i)di = \int_{f_s}^{1} \frac{P_S S}{p_s(i)}di = (1-f_s)\frac{\alpha Y}{w_s} = \frac{\alpha RY}{w_s^2}.$$

The demand for unskilled labor is equal to:

$$\int_{f_n}^{1} n(i)di = \int_{f_n}^{1} \frac{P_N N}{p_n(i)}di = (1-f_n)\frac{(1-\alpha)Y}{w_n} = \frac{(1-\alpha)RY}{w_n^2}.$$

Equating the supplies and demands yields the equilibrium conditions (16) and (17).

Derivation of Expected Utilities

The ex-post utility of a person with net income j in first period of life is

$$\frac{2+\rho}{1+\rho}\log j + \frac{\log R + (1+\rho)\log(1+\rho) - (2+\rho)\log(2+\rho)}{1+\rho}.$$

Hence, utility is a linear transformation of $\log j$. The expected log of income of a skilled worker before efficiency is realized is:

$$\int_0^v \log[vw_n(1-t)]de + \int_v^1 \log[ew_n(1-t)]de = \log w_n + \log(1-t) + v - 1.$$

This proves equation (22). Ex-ante expected log income of skilled is calculated similarly.

Analysis of the Effect of Minimum Wages

Assume a similar model to the one in section 2, except for the following differences. First, all skilled workers have efficiency 1. Second, unskilled workers have the same distribution of efficiency as in the benchmark model, but a worker's efficiency e is unknown both to the worker and to the employer. It can be observed by the employer only if the worker is monitored and only a proportion m of workers is monitored. We also assume that unskilled firms are sufficiently large so that the distribution of workers' efficiencies within each firm is the same as the aggregate distribution. Clearly, despite the different levels of efficiency unskilled workers are paid the same wage w_n due to asymmetry in information. Finally, assume that there is minimum wage regulation that sets the wage of unskilled to be at some ratio with the skilled wage:

(A.5) $$w_n = g w_s .$$

To derive the equilibrium we look at an employer who uses unskilled labor to produce an intermediate good. The employer knows the efficiency of m of the workers and fires a worker with efficiency e if: $e p_n(i) < w_n$. Hence, the upper bound for firing unskilled workers is $E_n(i)$, which is equal to:

$$E_n(i) = w_n / p_n(i).$$

The unskilled workers who are left in production are therefore those who have higher efficiency or those who have not been monitored.

Next consider technology adoption. In the skilled sector technology depends on comparing the cost of machine production to the cost of a worker, which is also the cost of one efficiency unit. Hence, the technological threshold in the skilled sector is:

(A.6) $$\frac{R}{1-f_s} = w_s .$$

In the unskilled sector a producer shifts to the industrial technology if the unit cost of producing by machines is lower than the average unit cost of producing by labor. Hence, the technology frontier at the unskilled sector is determined by:

(A.7) $$\frac{R}{1-f_n} = \frac{m\int_{E_n(i)}^{1} w_n de + (1-m)\int_0^1 w_n de}{m\int_{E_b(i)}^{1} e de + (1-m)\int_0^1 e de} = 2\frac{w_n - m\dfrac{w_n^2}{p_n(i)}}{1-m\dfrac{w_n^2}{p_n^2(i)}}.$$

To derive the equilibrium price of an unskilled intermediate good produced by labor, note that profits are driven to zero by free entry, so the price must equal the average cost. It follows from (A.7) that:

(A.8) $$p_n(i) = 2\frac{w_n - m\dfrac{w_n^2}{p_n(i)}}{1-m\dfrac{w_n^2}{p_n^2(i)}}.$$

Solving (A.8) shows that the price is equal to: $p_n(i) = p_n = x w_n$ where x is:

$$x = 1 + \sqrt{1-m}.$$

Hence the technology frontier in the unskilled sector is described by:

(A.9) $$\frac{R}{1-f_n} = xw_n,$$

Given that the ratio between the unskilled and skilled wages is g due to wage compression, we get:

(A10) $$f_s = 1 - gx(1-f_n).$$

An increase in g reduces f_s and w_s and raises f_n and w_n. Hence, the effect of labor force regulation on technical change is the same as in the benchmark model. Note that without minimum wage regulation the free market equilibrium wage ratio, I_e is given by:

$$L_n\left(1-\frac{m}{x}\right) = \frac{1-\alpha}{\alpha}\frac{L_s}{x^2 I_e^2}.$$

If g is higher than the equilibrium wage ratio, which is the case if it is effective, there are two types of unemployment of unskilled. There are $mE_n = m/x$ fired workers, and there are also workers who are not hired at all, since the unskilled wage rate is too high.

<u>Analysis of the Effect of Firing Costs</u>

Assume that the model is similar to the benchmark model except for one difference. Individual efficiency e is unknown to the worker, but is observed by the employer on the job. Assume that an employer can fire a worker, but this act is costly and the firing costs are h in terms of the final good. Also assume that firms are sufficiently large so that the distribution of workers' efficiencies within each firm is the same as the aggregate distribution. First note, that due to asymmetric information, both skilled and unskilled wages are equal for all workers, irrespective of efficiency. Consider next an employer who uses skilled labor to produce an intermediate good. Since the employer knows the efficiency of workers, he will fire those with efficiency e that satisfies: $ep_s(i) - w_s < -h$.

Hence, the threshold for firing skilled workers $E_s(i)$ is determined by:

(A.11) $$E_s(i) = \frac{w_s - h}{p_s(i)}.$$

The firing threshold in the unskilled sector is similar. It follows from (A.11) that to find the threshold for firing we need to find the equilibrium price of the intermediate good, which is produced by skilled labor. Note that profits are driven to zero due to free entry and hence price equals average cost per unit produced, including firing costs:

$$p_s(i) = 2\frac{(1-E_s(i))w_s + E_s(i)h}{1-E_s^2(i)}.$$

Together with (A.11) we get:

(A.12) $$p_s(i) = p_s = w_s + \sqrt{h(2w_s - h)},$$

and:

(A.13) $$E_s(i) = E_s = \frac{w_s - h}{w_s + \sqrt{h(2w_s - h)}} = 1 - \sqrt{\frac{2h}{p_s}}.$$

The results for unskilled goods are symmetric. Next, consider technology adoption. A producer shifts to industrial technology if the unit cost of producing by machines is lower than the average unit cost of producing by labor. Hence, the technological threshold is determined by:

(A.14) $$\frac{R}{1-f_s} = p_s.$$

The technological threshold in the unskilled sector is similar and in a similar way to the benchmark model we can derive the same "goods market equilibrium condition" as condition (9) in the benchmark model. In the Skilled sector we get:

(A.15) $$\frac{\alpha Y}{L_s} = \frac{\sqrt{\frac{2Rh}{1-f_s}} - h}{1-f_s}.$$

The equilibrium condition in the market for unskilled labor is similar. Thus:

(A.16) $$\frac{\sqrt{\frac{2Rh}{1-f_s}} - h}{1-f_s} = \frac{\alpha}{1-\alpha}\frac{L_n}{L_s}\frac{\sqrt{\frac{2Rh}{1-f_n}} - h}{1-f_n}.$$

This labor market equilibrium condition constitutes a positive relationship between f_n and f_s. Hence, together with the "goods market equilibrium condition" it determines a unique general equilibrium, as can be described in a diagram similar to Figure 1. Using it we can show that a rise in firing costs h increases f_n and lowers f_s.

Derivation of the Aggregate Production Function

The aggregate production function is defined as the maximum amount of output that can be produced by the given amounts of factors of production. The logarithm of output is equal to:

(A.17) $$\log Y = a + \alpha\int_0^1 \log s(i)di + (1-\alpha)\int_0^1 \log n(i)di.$$

The constraints on production, given the amounts of the factors of production, are:

(A.18) $$L_s^e = \int_{f_s}^1 s(i)di,\ \ L_n^e = \int_{f_n}^1 n(i)di,\ \ and\ K = \int_0^{f_s} \frac{s(i)}{1-i}di + \int_0^{f_n} \frac{n(i)}{1-i}di.$$

Maximizing (A.17) given the constraints (A.18) leads to the following optimal allocations:

(A.19)
$$s(i) = \frac{\alpha K}{\alpha f_s + (1-\alpha) f_n}(1-i)\quad for\ all\ 0 \le i \le f_s,$$
$$s(i) = \frac{L_s^e}{1-f_s}\quad for\ all\ f_s < i \le 1,$$
$$n(i) = \frac{(1-\alpha)K}{\alpha f_s + (1-\alpha) f_n}(1-i)\quad for\ all\ 0 \le i \le f_s,$$
$$n(i) = \frac{L_n^e}{1-f_n}\quad for\ all\ f_n < i \le 1.$$

Substituting (A.19) in (A.17) we get:

(A.20)
$$\begin{aligned}\log Y &= a + f_s\alpha(\log\alpha - 1) + f_n(1-\alpha)[\log(1-\alpha)-1] - 2\alpha(1-f_s)\log(1-f_s) - \\ &- 2(1-\alpha)(1-f_n)\log(1-f_n) - [\alpha f_s + (1-\alpha)f_n]\log[\alpha f_s + (1-\alpha)f_n] + \\ &+ \alpha(1-f_s)\log L_s^e + (1-\alpha)(1-f_n)\log L_n^e + [\alpha f_s + (1-\alpha)f_n]\log K.\end{aligned}$$

Hence, the aggregate production function is described by:

(A.21) $$Y = \exp[a + \varphi(f_s, f_n)]K^{\alpha f_s + (1-\alpha)f_n} L_s^{e\ \alpha(1-f_s)} L_n^{e\ (1-\alpha)(1-f_n)},$$

where:

(A.22)
$$\begin{aligned}\varphi(f_s, f_n) &= f_s\alpha(\log\alpha - 1) + f_n(1-\alpha)[\log(1-\alpha)-1] - 2\alpha(1-f_s)\log(1-f_s) - \\ &- 2(1-\alpha)(1-f_n)\log(1-f_n) - [\alpha f_s + (1-\alpha)f_n]\log[\alpha f_s + (1-\alpha)f_n].\end{aligned}$$

Maximization with respect to the technology frontiers leads to the following two optimal conditions:

(A.23) $$\alpha(1-f_s)^2 = \frac{L_s^e}{K}[\alpha f_s + (1-\alpha)f_n],$$

and:

(A.24) $$(1-\alpha)(1-f_n)^2 = \frac{L_n^e}{K}[\alpha f_s + (1-\alpha)f_n].$$

Note that these two equations are equivalent to the labor market equilibrium conditions, equations (16) and (17).

References

Acemoglu, D. (1998), "Why Do new Technologies Complement Skills?" *Quarterly Journal of Economics,* 113 (1998), 1055-1089.

Acemoglu, D. (2003a), "Cross-Country Inequality Trends," *Economic Journal*, 113, F121-149.

Acemoglu, D. (2003b), "Factor Prices and Technical Change: From Induced Innovations to Recent Debates," in *Knowledge, Information and Expectations in Modern Macroeconomics: In Honor of Edmund Phelps*, ed. by Philippe Aghion et al, Princeton University Press, Princeton NJ.

Acemoglu, D. and F. Zilibotti, (2001) "Productivity Differences," *Quarterly Journal of Economics*, 116, 563-606.

Alesina, A., R. Baqir, and W. Easterly (2000), "Redistributive Public Employment," *Journal of Urban Economics* 48: 219-41.

Alesina, A., S. Danninger, and M. Rostagno (2001), "Redistribution through Public Employment: The Case of Italy," *IMF Staff Papers* 48: 447-73.

Alesina, A., R. DiTella, and R. McCulloch (2004), "Inequality and Happiness: Are Europeans and Americans Different?" *Journal of Public Economics* 88: 2009-42.

Alesina A. and F. Giavazzi (2007) The *Future of Europe: Reform or Decline*, MIT Press Cambridge Mass

Alesina, A., and E. Glaeser (2004), *Fighting Poverty in the U.S. and Europe: A World of Difference*, Oxford University Press, Oxford, U.K.

Alesina, A., E. Glaeser, and B. Sacerdote (2005), "Work and Leisure in the U.S. and Europe: Why So Different?" *NBER Macroeconomics Annual*.

Autor D. F. Levy and R Murname (2003) "The Skill Content of Recent Technological Change: An Empirical Exploration" *Quarterly Journal of Economics* 1129-213.

Basu, S., and D. Weil, D. "Appropriate Technology and Growth," *Quarterly Journal of Economics*, 113 (1998), 1025-1054.

Beaudry P. and F. Collard (2001) "Why has the Employment Productivity Trade off amongst Industrialized Countries so strong?" *NBER Working Paper*

Bjorklund, A., and R. B. Freeman (1997), "Generating Equality and Eliminating Poverty, the Swedish Way," in R. B. Freeman, R. Topel, and B. Swedenborg (eds.), *The Welfare State in Transition: Reforming the Swedish Model*, Chicago: University of Chicago Press, 33-78.

Blanchard, O. J. (1997), "The Medium Run," *Brookings Papers on Economic Activity* 2: 89-141.

Blanchard, O. J. (2004), "The economic future of Europe," *Journal of Economic Perspectives*, 18: 3-26

Blanchard, O. J., D. Cohen, and C. Nouveau (2005), "The history of French labor market institutions since 1950," unpublished.

Blanchard, O. J., and L. F. Katz (1999), "Wage Dynamics: Reconciling Theory and Evidence," *American Economic Review* 89: 69-74.

Blanchard, O. J., and J. Wolfers (2000), "The Role of Shocks and Institutions in the Rise of European Unemployment: The Aggregate Evidence," *Economic Journal* 110: 1-33.

Blau, F., and L. Kahn (1996a), "International Differences in Male Wage Inequality: Institutions versus Market Forces," *Journal of Political Economy* 104: 791-837.

Blau, F., and L. Kahn (1996b), "Wage Structure and Gender Earnings Differentials: An International Comparison," *Economica* 63: S29-62.

Blau, F., and L. Kahn (1999), "Institutions and Laws in the Labor Market," in O. C. Ashenfelter and D. Card (eds.), *Handbook of Labor Economics*, Amsterdam: Elsevier, 1399-1461.

Blau, F., and L. Kahn (2002), *At Home and Abroad: U.S. labor markets in international perspective*, Russell Sage, New York, NY.

Boeri T. and P. Garibaldi (2007) "the two tier reforms of Employment Protection: A Honeymoon Effect" *Economic Journal* forthcoming

Caballero, R., and M. Hammour (1998), "Jobless Growth: Appropriability, Factor Substitution and Unemployment," *Carnegie-Rochester Conference Series on Public Policy*, 48: 51-94.

Champernowne, D. (1963). "A Dynamic Growth Model Involving a Production Function," in F.A. Lutz and D.C. Hague, eds., *The Theory of Capital* New York: Macmillan, 1963

Comin, D. and B. Hobijn's (2004), "Cross-Country Technology Adoption: Making the Theories Face the Facts", *Journal of Monetary Economics* 51: 38-83.

Comin, D. and B. Hobijn (2006), "Lobbies and Technology Diffusion", New York University mimeo.

Dornbusch, R. R. Gentilini, and F. Giavazzi (2000), "Italian Labor Force Participation: Disguised Unemployment on Campus," unpublished.

Edin, P.-A, and R. Topel (1997), "Wage Policy and Restructuring: The Swedish Labor Market since 1960," in R. B. Freeman, R. Topel and B. Swedenborg (eds.), *The Welfare State in Transition: Reforming the Swedish Model*, Chicago: University of Chicago Press, 155-201.

Freeman, R. B., and L. F. Katz, eds. (1995), *Differences and Changes in Wages in Wage Structures*, Chicago: University of Chicago Press.

Glyn A. J. Moeller, W. Salverda, J Scmitt, and M. Sollogoub (2007) "Employment Differences in Services: The Role of Wages Productivity and Demand" in M. Gregory and W. Salverda and R. Schettkat (es) *Service Inculded? Services and the European-Amercoan Employment Gap, forthcoming* Cambridge University Press Cambridge UK

Gottschalk, P., and T. Smeeding (1997), "Cross National Comparisons of Earnings and Income Inequality," *Journal of Economic Literature*, 35: 633-87.

Kahn, L. M. (1998a), "Against the Wind: Bargaining Recentralization and Wage Inequality in Norway, 1987-1991," *Economic Journal* 108: 603-45.

Kahn, L. M. (1998b), "Collective Bargaining and the Inter-industry Wage Structure: International Evidence," *Economica* 65: 507-34.

Kahn, L. M. (2000), "Wage Inequality, Collective Bargaining, and Relative Employment, 1985-94: Evidence from 15 OECD Countries," *Review of Economics and Statistics* 82: 564-79.

Katz, L. F., and K. M. Murphy (1992), "Changes in Relative Wages, 1963-1987: Supply and Demand Factors," *Quarterly Journal of Economics* 107: 35-78.

Koeniger, Winfried, and Marco Leonardi, "Capital Deepening and Wage Differentials: Germany versus US," *Economic Policy*, 2007, 3-46.

Kramarz, F. (2007), "Outsourcing, Unions, Wages, and Employment: Evidence from Data Matching Imports, Firms and Workers," mimeo.

Lazear, E. P. (1990), "Job Security, Provisions and Employment," *Quarterly Journal of Economics* 105: 699-726.

Lewis, E. (2005), "Immigration, Skill Mix, and the Choice of Technique," *Federal Reserve Bank of Philadelphia Working Paper.*

O'Mahony, M. and B. van Ark (2003), eds., *EU Productivity and Competitiveness: An Industry Perspective Can Europe Resume the Catching-up Process?* Office for Official Publications of the European Communities, Luxembourg.

Parente, S.L., and E. Prescott, "Barrier to Technology Adoption and Development," *Journal of Political Economy*, 102 (1994), 298-321.

Pissarides C. (2006) "Lisbon Five Years Later" Keynote Address at the Austrian Government Conference on Innovations in Labor Market Polices, February

Prescott, E. (2004), “Why Do Americans Work So Much More than Europeans?” *Federal Reserve Bank of Minneapolis Quarterly Review*, 28: 2-13.

Rogerson R. (2007) “Structural Transformations and the Deterioration of European Employment Outcome” NBER Working paper.

Rogerson, R. and J. Wallenius (2007), “Micro and Macro Elasticities in a Life Cycle Model with Taxes,” mimeo.

Saint-Paul G. (2006) “Distribution and Growth in an Economy with Limited Needs” *Journal of the European Economic Association, forthcoming*

Zeira, J. (1998), “Workers, Machines and Economic Growth,” *Quarterly Journal of Economics*, 113, 1091-1113.

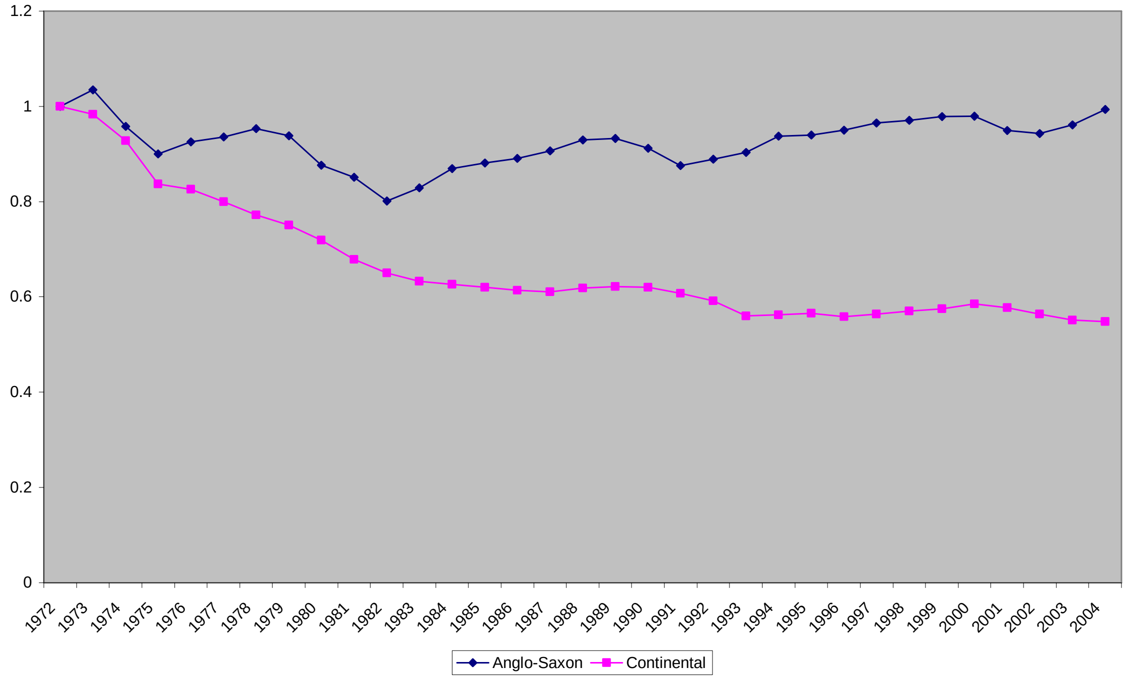
Zeira, J. (2006), “Machines as engines of growth,” unpublished.

Zuleta, H. (2006), “Why Factor Income Shares Seem to be Constant?” unpublished.

Figure 3

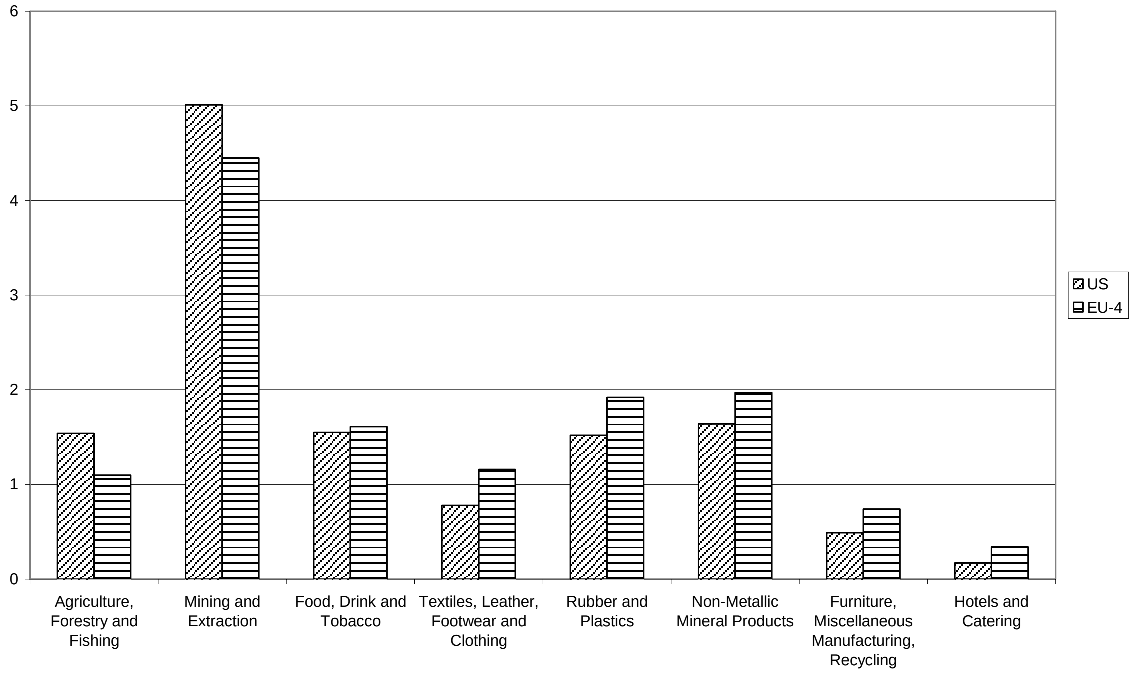
Labor/Capital Ratio in "Continental" and "Anglo-Saxon" Countries

(Index, 1972=1)

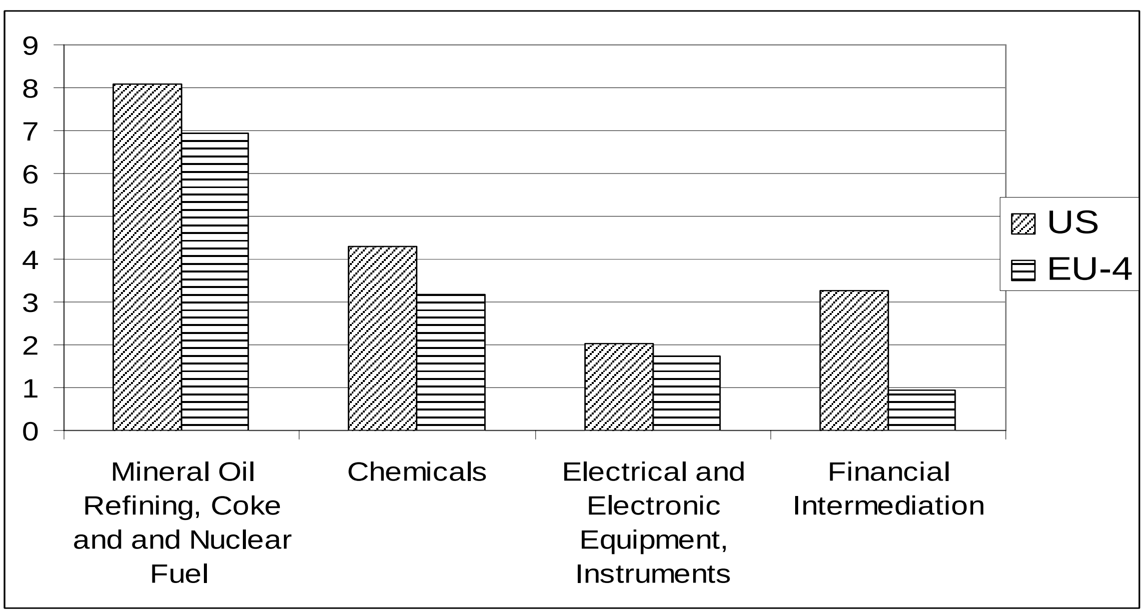


Source: Own calculations, based on data from the OECD Economic Outlook, December 2005. The computation is based on Blanchard (1997, p. 96), following the codes that he kindly provided, and the sample of countries is essentially the same as in that paper. However, some differences are worth mentioning: 1- Updated data set; 2- Australia is excluded, due to lack of data necessary to compute the GDP of the business sector; 3- We start in 1972, so that the sample of countries is exactly the same in every year (some countries have missing data before that year); 4- Cross-country averages weight countries in proportion to 2000 GDP in PPP units. Anglo Saxon countries are: US Canada and UK; Continental are Austria, Belgium, Denmark, France, West Germany, Ireland, Italy, Netherlands, Spain, and Sweden.

Figure 4: Capital per Hour Worked, 2000, US and EU-4



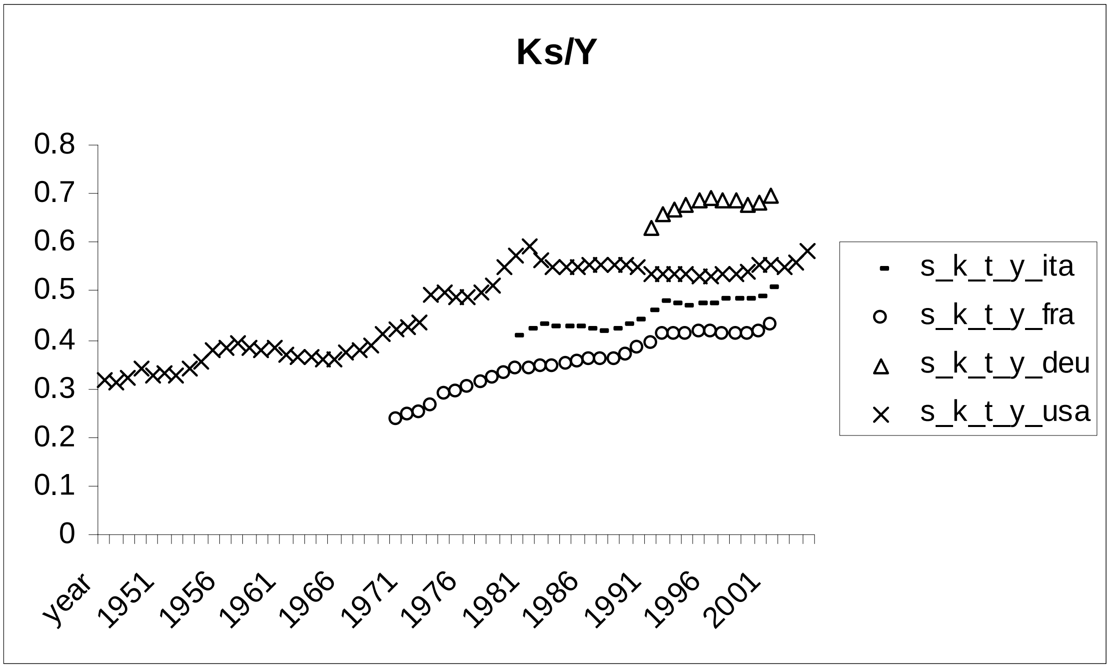
a. Low-Skill Sectors



b. High-Skill Sectors

Figure 5

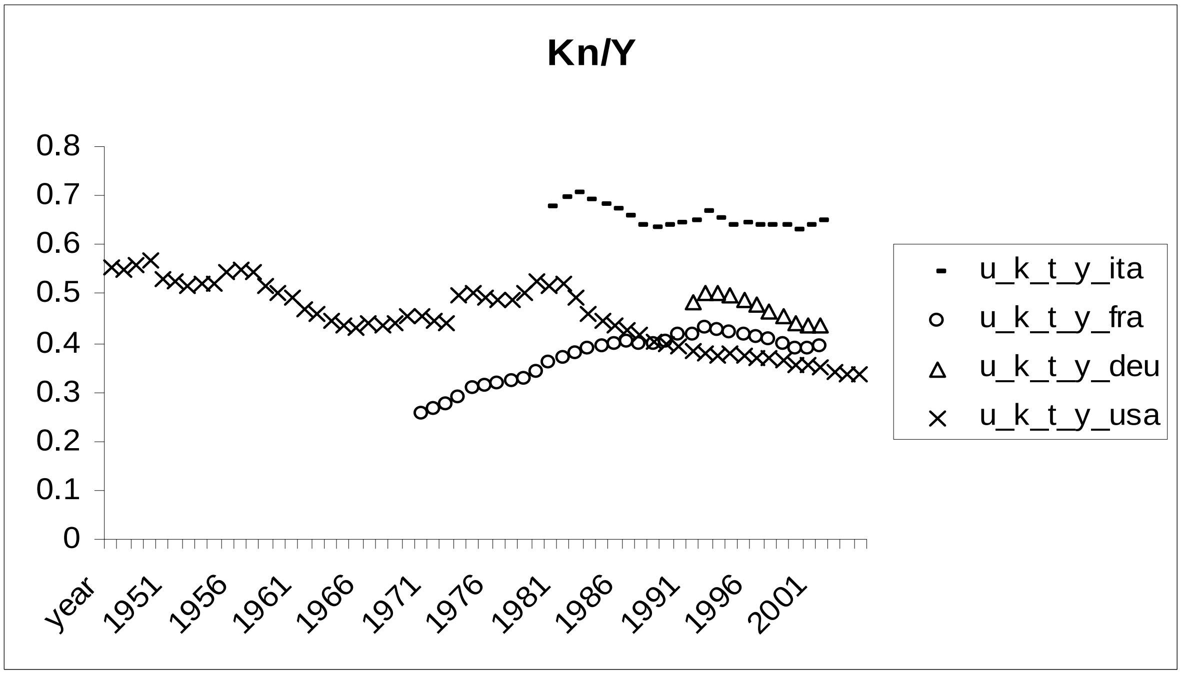
Ratio of Capital in Skilled Sectors to Output in US, France, Italy, and Germany



Source: OECD for France, Italy and Germany, BEA for the US.

Figure 6

Ratios of Capital in Low Skilled Sectors to Output in US, France, Italy and Germany



Source: OECD for France, Italy and Germany and BEA for the US.

Figure 7

Ratios of Capital to Value Added in Low Skilled Sectors in the US and Europe

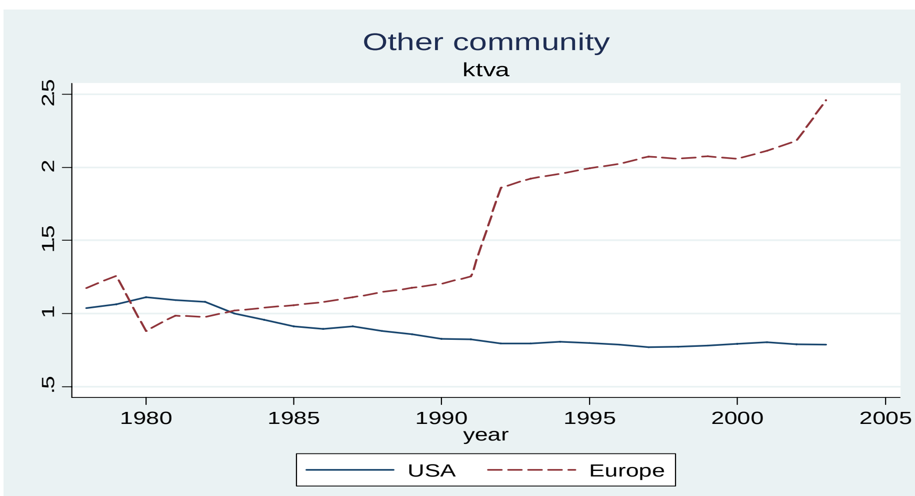
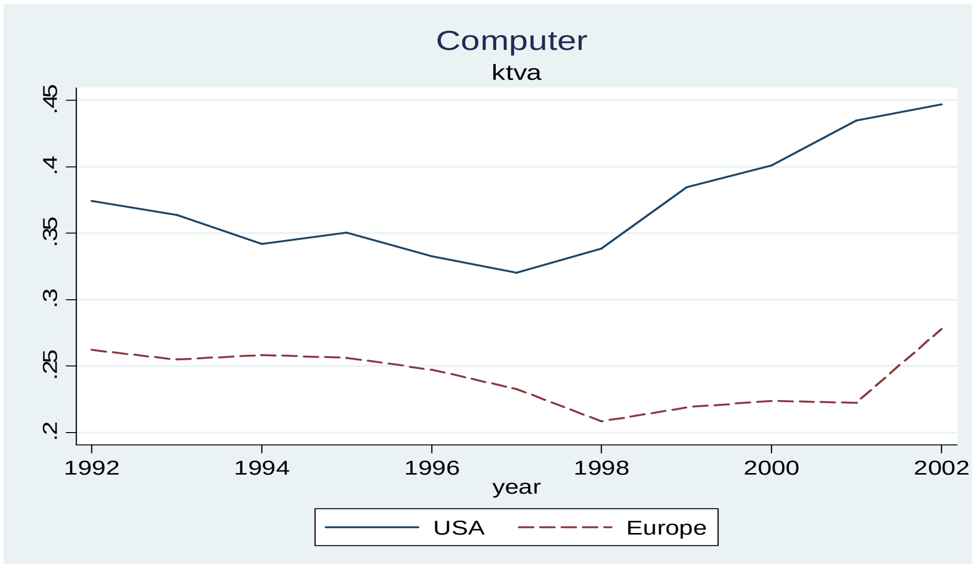


Figure 8

Ratios of Capital to Value Added in High Skilled Sectors in the US and Europe



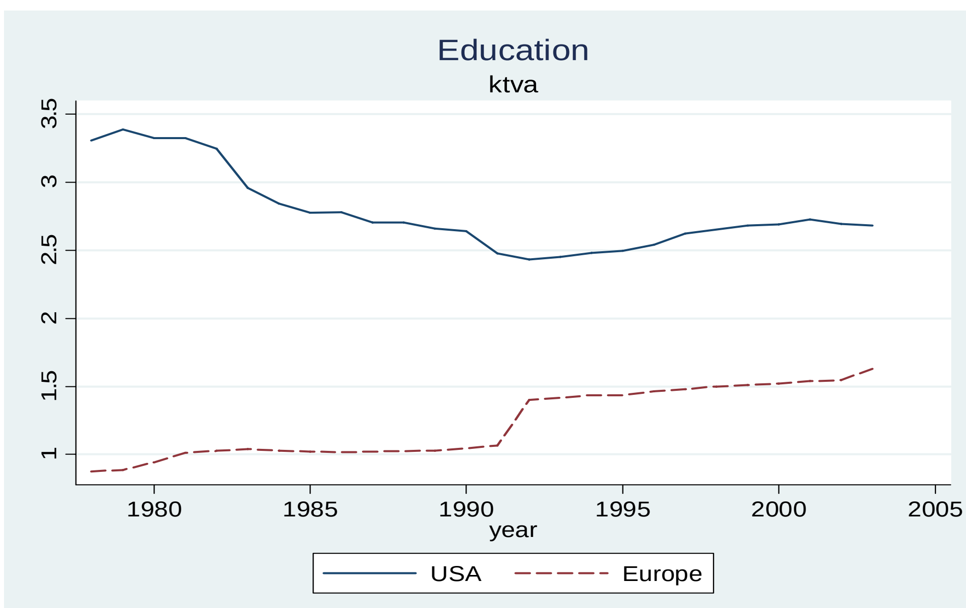
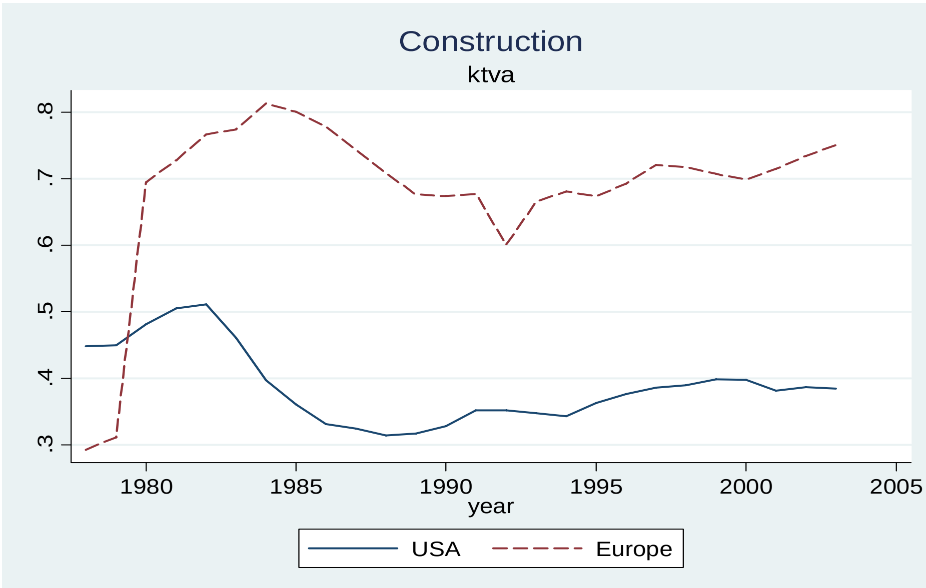


Figure 9

Ratios of Capital to Value Added in Low Intermediate Skilled Sectors in the US and Europe



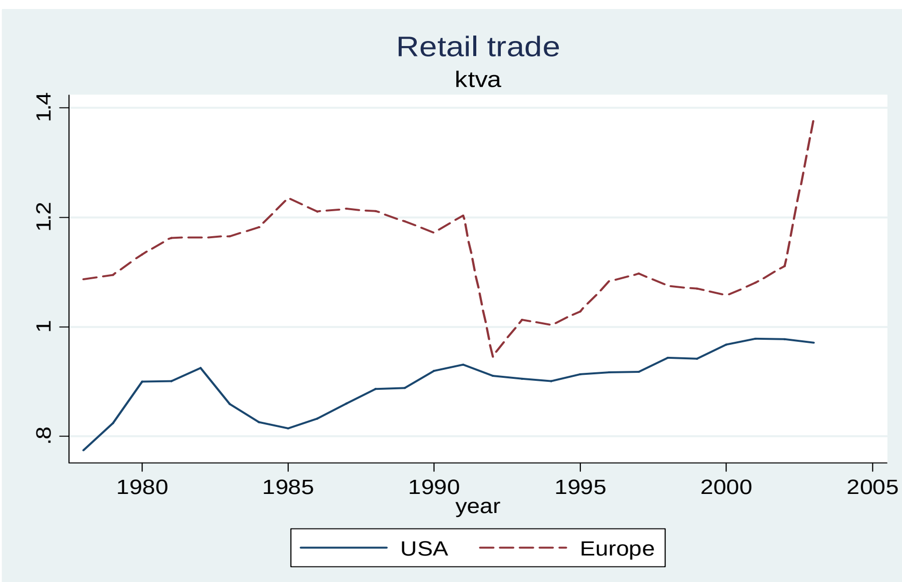
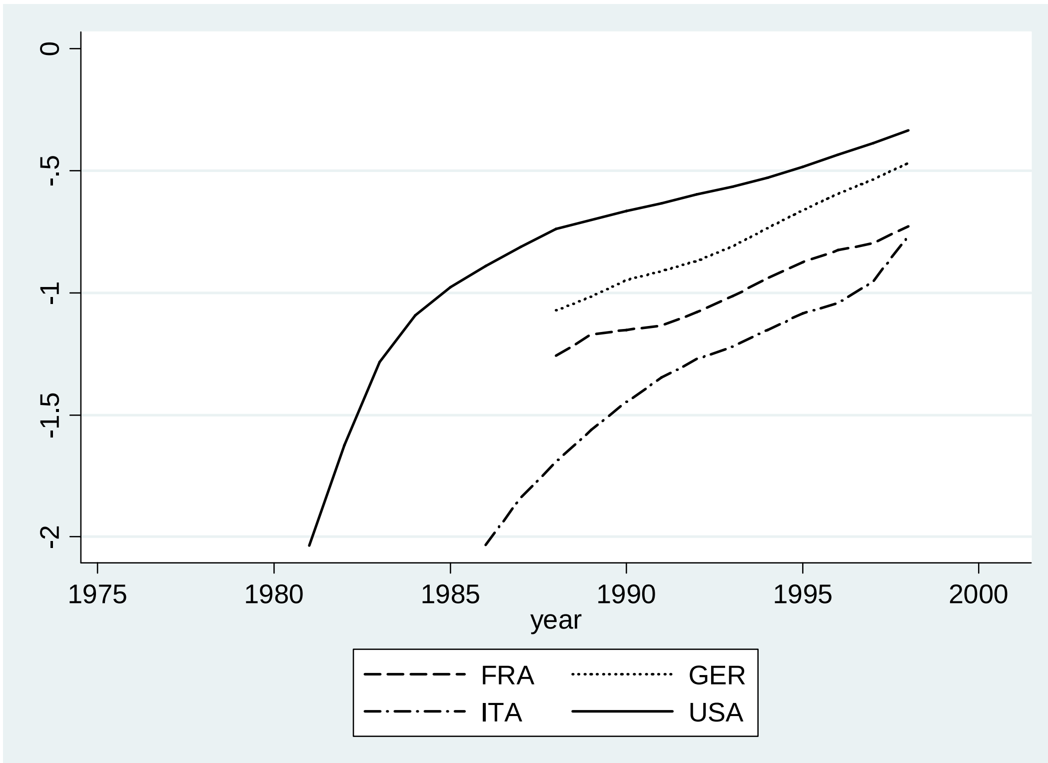


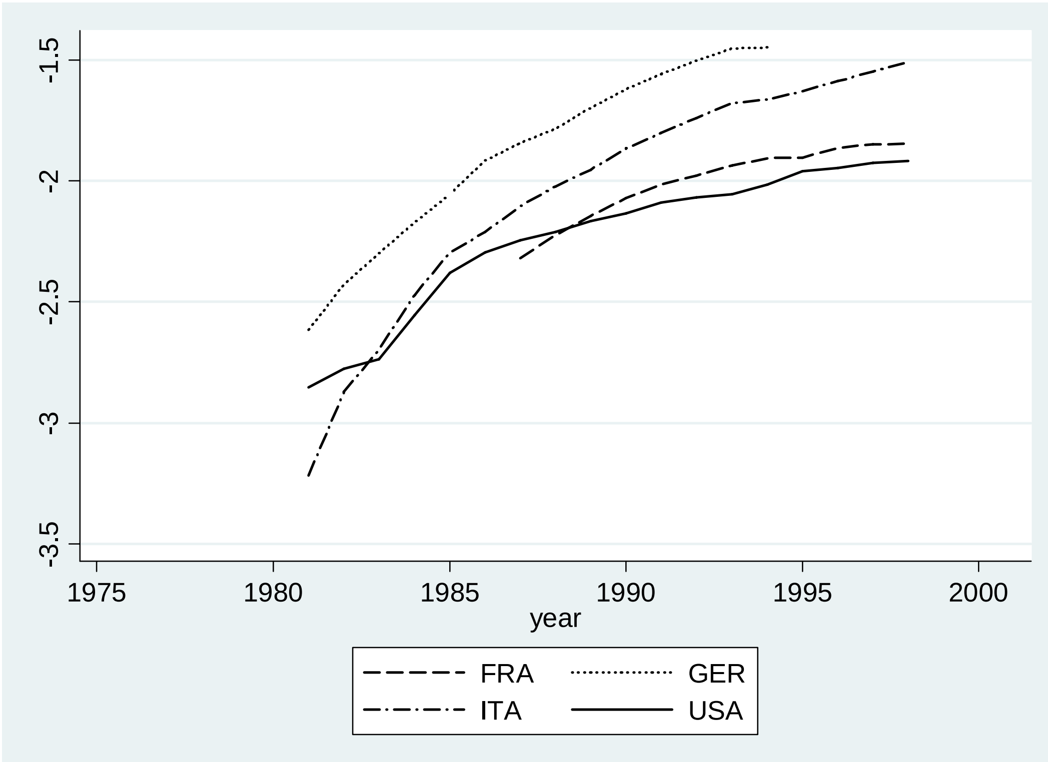
Figure 10
Personal Computers per capita
(in logs)



Source: HCCTA.

Figure 11

Industrial Robots as share of GDP
(in logs)



Source: HCCTA.