Technology and Labor Regulations

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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 progress in the US is more skill biased than in Europe, since American skilled wages are higher.

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 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. Why?

This paper proposes a model which answers this question. It suggests that the main difference between Europe and the US that leads to such technological differences is their different labor market policies. European countries reduce wage flexibility and wage inequality through a host of labor market regulations, like binding minimum wage laws, permanent unemployment subsidies, firing costs, etc. These 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 progress in the US is more skill biased than in Europe, since American skilled wages are higher.

There are only a few ways to model differential technology adoption across countries. One is to assume that technology adoption is costly, like Parente and Prescott (1995). This approach may help in understanding gaps between rich and poor countries, but it does not fit our case, since if adoption costs in Europe were higher, we should observe less technical progress in all sectors, which is not the case. Basu and Weil (1998) and Acemoglu and Zilibotti (2001) suggest instead that technology adoption depends on supplies of factors of productions, as different technologies fit better different factors of production. But as we show in the paper, this approach cannot account for the observed differences between Europe and the US. Actually it implies that the region with more skill biased technical change should be the one with a lower skill premium.[1] We therefore resort to the third approach, following Champernowne (1963) and Zeira (1998, 2006), which models technological change as substituting labor by machines. According to this approach technological innovations reduce labor but require purchasing machines, namely increasing capital. Hence, such technological innovations are invented and adopted only if wages are sufficiently high, so that they reduce the cost of production.

In this paper we consider a model of two sectors, skilled and unskilled, and we show that the wage in each sector determines the degree of technical progress in that sector. The model allows the US and Europe to differ in their supplies of skill and in labor market policy. The model then shows that greater labor regulation in Europe, in the form of unemployment benefits, leads to reduction in the skill premium in Europe, to less skill-biased technical change, but also to more technical progress in the unskilled sector. This is shown not only with respect to unemployment benefits, but for other types of labor regulation as well, like minimum wages or firing costs.

The different labor market policies followed in US and in Europe have already been the focus of much economic research, especially since the two areas started to diverge in performance since the nineteen seventies, which were years of turmoil and high unemployment in both. Since then unemployment in Europe has shown a tendency to remain high, while unemployment in the US has declined steadily. This difference was

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[1] See Section 3.

attributed by many economists to different labor market policies.[2] Unemployment has been just part of the story. The number of work hours per person has steadily declined in Europe (especially France, Germany and Italy) since the mid seventies relative to the US.[3] Alesina, Glaeser and Sacerdote (2005) argue that the main explanation to it is union imposed work regulations and employer/union collective agreements on hours worked.[4] Our model is consistent with this.

Many economists have attributed the large rise in the wage skill differential in the US to skill biased technical change.[5] 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 process, the deregulation of markets in the US and the decline in labor unions' strength. It therefore raises the hypothesis of some reverse causality, namely that the rise of the wage differential in the US has contributed to skill biased technical change. At the very least the technological revolutions in the US would have been seriously impeded if the labor market environment would have been similar to that of Europe, or with stronger unions and less deregulation.

In summary, the paper suggests that the decline in labor unions' power and the reduction in labor market regulation in the US have been one of the causes of lower

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[2] See Blau and Kahn (1996, 2002) and Freeman and Katz (1995). Blanchard and Wolfers (2000) and recently Ljungqvist and Sargent (2006) amongst many others also point towards labor regulation and especially firing costs as the major explanation of recent development of European unemployment but not directly through the technological channel.

[3] This decline has been in part lower participation in the labor force, in part longer vacations, and in part shorter work weeks.

[4] Alesina et al (2005) also discuss additional explanations, like the increase in marginal tax rates, emphasized by Prescott (2004), and preference for leisure, stressed by Blanchard (2004). They conclude that while these other explanations also play some roles, the lion's share is due to the direct and indirect effects (via social multipliers) of labor regulations.

[5] 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).

unemployment, higher wage inequality and more skill biased technical change, while opposite policies in Europe led to higher unemployment, lower wage inequality, and more technical progress at low skilled sectors. Note that even though labor market regulations distort technological adoption and employment, to some degree they may not be sub-optimal in an ex ante sense, for insurance (of the workers) purposes. This result, which in general is of course not new, holds even in our model, where labor regulation distorts technological adoption. Interestingly, a simulation analysis we conduct, which builds on actual skill supplies in Europe and the US, points at a possibility that labor regulation in the US is lower than optimal, while in Europe it is higher than optimal. This is raising the possibility that there is a significant difference in social preferences across the Atlantic, as emphasized by Alesina and Glaeser (2004).

The paper stresses the idea that a high cost of labor may lead to labor saving technologies. Some elements of this idea already appear in other studies. Blanchard (1997) mentions substitution of labor by capital as one of the explanations for high unemployment in Europe. Caballero and Hammur (1998) use a similar idea but they do not focus on the low versus high skill differences. Beaudry and Collard (2001) investigate how endogenous changes in an AK technology may affect the employment- productivity trade-off and explain the degree of convergence across industrial economies. Saint Paul (2006) studies the effect of changes in technologies on distribution amongst factors. Lewis (2005) discusses the low skilled versus high skilled relative supply in the US context but does not explore the role of labor market regulation and focuses on relative supplies of the two type of labor.

The paper is organized as follows. Section 2 presents the basic model. Section 3 compares the results to some alternative literatures. Section 4 presents extensions to other types of labor market regulations. Section 5 discusses some empirical implications of the model. The last section concludes and the appendix contains mathematical derivations of some results.

2. The Basic Model

2.1 The Set-Up

The population in this economy lives in overlapping generations. The size of each generation is normalized to be 1. Each individual is born to a single parent, lives two periods and has a single offspring. Individuals work in first period of life only. An individual can work as skilled if studies, or as unskilled if does not study. For simplicity assume that if an individual is born to a skilled parent learning is costless, but if born to an unskilled parent learning is infinitely costly. As a result the groups of skilled and unskilled are fixed over time.[6] Denote by L_n the share of unskilled and by L_s be the share of skilled, so that: $L_n+L_s = 1$. In addition to being skilled or unskilled each person has individual efficiency e, which is random, distributed uniformly between zero and 1, and is independent of whether the individual is skilled or unskilled. People derive utility from consumption in the two periods of life:

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

where $\rho > 0$.

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

There is a single final good in the economy, which is used for both consumption and investment. It is produced by two intermediate goods, the skilled good *S* and the unskilled *N*, using the following production function:

(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 an old manual technology, where a unit of *i* is produced by 1 efficiency unit of skilled labor. The second is an industrial technology that produces *i* by a machine. This machine is of size or cost $k(i)$ and it can replace the worker and produce a unit of *i* as well. Capital, namely machines, is fully depreciable within 1 period and innovation is costless, so if there is demand for a machine it is invented. Hence, the only cost of the industrial technology is the cost of the machine. It is assumed that this cost $k(i)$ is rising with *i*.[7] 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) $$\log N = a + \int_0^1 \log n(i)di.$$

[7] This is just an ordering assumption and has no effect on the analysis.

Each unskilled intermediate good is 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), namely the two sectors are symmetric.[8]

The economy is open to capital mobility and small, so that the world interest rate is given and equal to r. We denote the gross interest rate by $R = 1 + r$. To simplify things assume that the economy trades only in the final good, and not in skilled, unskilled and intermediate goods. Also assume that educated people work as skilled but can work as unskilled as well, while people without education (children of unskilled) cannot work as skilled.[9]

Finally assume that there is an unemployment compensation, or a more general social insurance system, and if someone is out of job, she is entitled to v times the wage of unskilled, where $v < 1$. This parameter measures the degree of labor market regulation. In Section 5 we discuss other forms of labor market regulation. The transfer payments are financed by a tax on income, at a fixed rate t, which keeps the budget balanced. To keep the algebra simple assume that the tax is paid on the transfer payments as well.

2.2 Technology Adoption

We begin with a derivation of technical progress in the two sectors of the economy. Denote by w_n the gross wage rate per efficiency unit of an unskilled worker and by w_s the gross wage rate of an efficiency unit of a skilled worker. First, a skilled intermediate good is industrialized and produced by machines, if the cost of a machine is lower than that of labor, namely if:

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[8] We can assume that the sectors are not symmetric, where the cost of a machine that replaces a skilled worker is $b_s/(1-i)$, and the cost of a machine that replaces an unskilled workers is $b_n/(1-i)$. The qualitative results of the model in this case are the same.

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

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

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:

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

In a similar way the unskilled intermediate goods $i \leq f_n$ are produced by machines, where the technology frontier for unskilled is:

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

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

We next turn to determine prices and wages. 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 cost, due to free entry and constant returns to scale. Hence, prices of the intermediate goods in the skilled sector are:

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

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

The ε serves as notation for the term $\alpha \log \alpha + (1-\alpha)\log(1-\alpha)$. We call equation (9) the "goods markets equilibrium condition." Note that it describes a trade off between the technology frontiers in the two sectors.

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 strongly related to the degrees of technical progress in the two sectors:

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

Hence, we get the following relationship between the two technology frontiers:

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

We call it the "labor market constraint."

Together, the equations (9) and (10) determine the equilibrium values of technical progress and wages in each sector given the wage ratio between the two sectors. This is shown in Figure 1, which presents their intersection. The **G** curve describes the goods market equilibrium condition (9), while the **L** curve describes the labor market constraint (10). Note that due to our assumption that skilled workers can always switch and work as unskilled the wage ratio I satisfies: $1 \le I < \infty$.

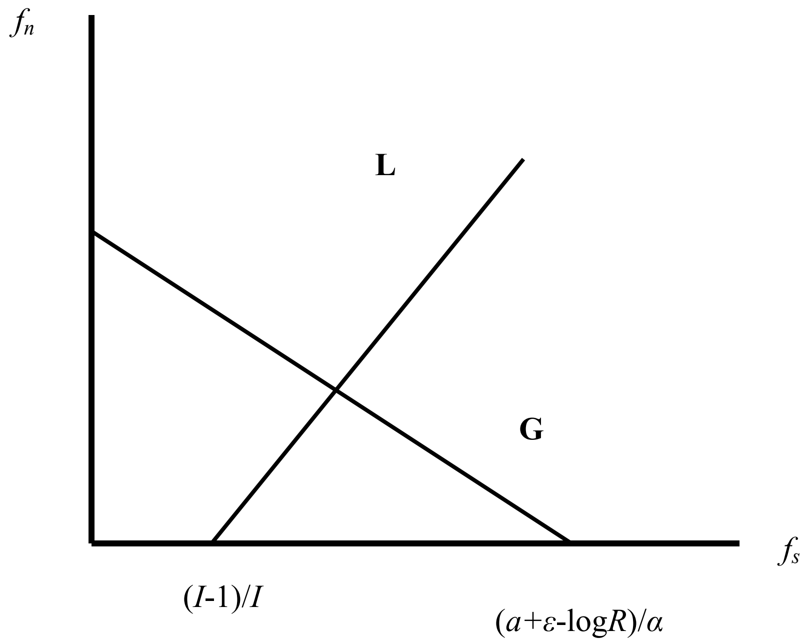

Figure 1: Determination of Technology Frontiers

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

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

and:

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

Note that the equilibrium is described by (11) and (12) only if there are no corner solutions. A sufficient condition that there is no corner solution at any wage inequality I between 1 and infinity is that the basic productivity a satisfies:

$$\alpha + \log R - \varepsilon \le a \le 1 + \log R - \varepsilon.$$

We next examine the effect of inequality I on technology. As wage inequality I increases, the curve **L** shifts down, reducing f_n and increasing f_s. This is clear from equations (11) and (12) as well. Hence wage inequality induces technical progress in the skilled sector but reduces technology adoption in the unskilled sector. As a result, the wage of skilled workers rises and the wage of unskilled workers declines.

Consider the effect of a change in productivity a. This shifts curve **G**. Hence, a country with higher productivity has higher technical progress in both sectors, skilled and unskilled. Hence, if this model applies, and if technical progress in Europe is higher than in the US in the unskilled sector and lower in the skilled sector, this cannot be a result of differences in basic productivity between the two regions, but only a result of differences in wage inequality I, or in labor market institutions. We return to this point below, where we find how wage inequality is determined.

2.3. Equilibrium Wage Inequality

We next discuss the two labor markets, for skilled and unskilled, in order to derive the wage ratio I and find the equilibrium. Workers care only about their net income, as is clear from the utility function (1). A skilled worker with efficiency e earns ew_s before tax, while an unskilled worker with efficiency e earns ew_n. A worker chooses to work only if her earnings exceed the welfare payment. Hence an unskilled decides to work only if:

$$ew_n(1-t) \geq vw_n(1-t).$$

As a result, the unskilled $[v, 1]$ work and their rate of unemployment is

(13) $$u_n = v.$$

A skilled supplies labor if:

$$ew_s(1-t) \geq vw_n(1-t).$$

Hence, the rate of unemployment among the skilled is

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

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

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

The equilibrium in the market for unskilled labor is reached at:

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

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

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

We assume that $\alpha L_n/[L_s(1-\alpha)] \geq 1$ since it must hold anyway. Otherwise the supply of skilled is too large and the right hand side of (17) is lower than 1. In this case skilled workers turn to unskilled jobs, which pay a higher wage, and that drives wage inequality up to 1. Hence, the actual L_s falls and the condition is restored. This assumption implies both that wage inequality exceeds 1, and that it depends negatively on the degree of labor market regulation *v*.

2.4. The Effect of Unemployment Compensation

We can now analyze the general equilibrium effect of an increase in labor regulation v. A country with a larger unemployment compensation v has a lower wage inequality I. The intuitive reason is that it affects the unskilled workers by much more than the skilled ones. As a result this country has less technical progress in the skilled sector, namely f_s is lower, but has more technical progress in the unskilled sector, namely f_n is higher and in this country w_s is lower and w_n is higher.

It is interesting to note that the effect of labor regulation on wage inequality works through the effective supplies of skilled and unskilled labor. Unemployment compensation reduces the supply of unskilled by more that the supply of skilled. As a result it reduces the wage ratio, as due to equations (15) and (16) I^2 is equal to $\alpha/(1-\alpha)$ times the ratio of the effective unskilled supply to the effective supply of skilled in efficiency units. This observation has interesting implications when we compare Europe with the US. Wage inequality is higher in the US than in Europe, but high-education rates are higher in the US than in Europe. Hence our interpretation is that the wage ratio is lower in the US due to labor regulation. That means that there is effectively a larger ratio of skilled to unskilled in Europe than in the US, since many of the unskilled in Europe do not work. In Section 5 we present some empirical findings that support this observation.

2.5. Capital and Labor-Capital Complementarities

In this model machines replace workers. The substitution of labor by capital is therefore a major issue in our analysis. But capital is also complementary to labor, since some intermediate goods are still produced by labor. As a result capital in production of the goods $[0, f]$ is complementary to the workers producing the remaining intermediate goods

(f, 1] and increases their marginal productivity. We next calculate the aggregate amounts of capital used in production. Capital in the skilled sectors is:

$$K_s = \int_0^{f_s} \frac{s(i)}{1-i} di = f_s \frac{P_S S}{R} = \alpha f_s \frac{Y}{R}. \tag{18}$$

Similarly Capital in the unskilled sector is:

$$K_n = \int_0^{f_n} \frac{n(i)}{1-i} di = f_n \frac{P_N N}{R} = (1-\alpha) f_n \frac{Y}{R}. \tag{19}$$

From these equations it follows that 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. We examine these predictions empirically in Section 5. Note also that the positive relationship between wage inequality and the relative capital in the skilled sector is observationally equivalent to capital-skill complementarity.

2.6. Output and Fiscal Policy

In this economy unemployment among unskilled is higher than among skilled. The aggregate unemployment rate is equal to:

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

It can be shown that unemployment rises with v. The level of output in the economy can be calculated by use of equation (15):

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

It follows that labor market regulation v reduces output. An increase in v reduces I and reduces w_s. Hence output declines. The reason is the reduction in labor supply.

A balanced budget policy in this economy requires setting a tax rate that satisfies:

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

Note that if v is higher I is lower and w_n is higher. Hence if v is higher both unemployment is higher and the compensation per unemployed is higher, so that the overall amount of compensation, namely the right hand side of (21) is higher. Since output or income is lower, the tax must be higher. This is of course not surprising, since larger transfer payments require higher taxes. Next we examine the combined effect of transfers and taxes on welfare.

2. 7. Welfare Considerations

In this sub-section we examine the ex-ante expected utility of each person at birth, before her efficiency is known, as this is the correct measure of welfare. This is actually the average utility of skilled and unskilled in each generation. In the appendix we show that utility is a simple linear transformation the logarithm of net income, and since we are interested only in comparing utility we will use the expected logarithm of net income as a measure for expected utility from here on. The appendix shows that the expected ex-ante welfare of an unskilled worker is equal to:

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

The expected ex-ante welfare of a skilled worker is equal to:

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

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.

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

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

The calculation of average utility is quite complicated and we resort to simulations. For that, we must specify reasonable values for the four basic parameters of the model: the productivity parameter a, the gross interest rate R, share of skilled labor in the production of the final good α, and share of skilled workers in the population L_s.

Our choice parameters is guided by our main interest in comparing the US and Europe. We assume that there is little difference between them in interest rates and production parameters, so that our exercise centers on comparing equilibrium outcomes across different values of L_s, keeping the other parameters fixed. To choose the values of L_s note that the percentage of the population between ages 15 and 64 that had completed tertiary education in 1995 was 33% in the US and 17% in Europe, where "Europe" is taken to be the average of France, Germany, and Italy.[10] Thus US is represented by $L_s =$ 0.33, and Europe is represented by $L_s = 0.17$. As for the remaining parameters, $R = 2$ is a realistic interest rate for a period of one generation. To set α note that the ratio of wages of college graduates and high school graduates in the US has been 1.9 in the late 1990s, as shown by Autor, Katz, and Kearney (2005). Hence, according to equation (17), α must be higher than .64. We therefore set $\alpha = 2/3$. Finally, the productivity parameter a is set to satisfy the condition for an interior solution $\alpha + \log R - \varepsilon \le a \le 1 + \log R - \varepsilon$. This implies $1.99 \le a \le 2.33$, so we set $a = \log(8) \sim 2.08$.

[10] See Barro and Lee (2001).

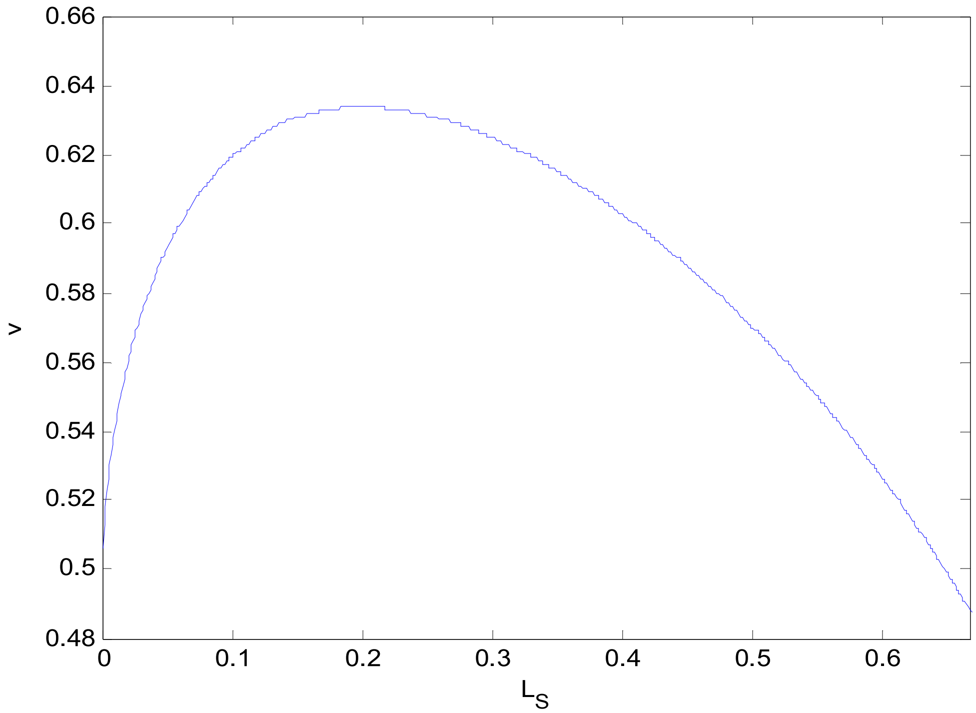

Figure 2: Optimal Unemployment Compensation

Figure 2 shows how optimal *v*, which maximizes AVG (*U*), changes with the amount of skill. Note that Figure 2 is drawn for $L_s \leq 2/3$, since this is implied by the constraint $\alpha L_n /(1-\alpha)L_s \geq 1$, which is required by $I \geq 1$. The relationship in Figure 2 is not monotonic, but it is clear though that for any amount of skill the optimal value of *v* is positive. Hence, labor market regulation increases welfare by supplying insurance against being born with low efficiency.[11]

[11] Note here that we can consider a Pareto-dominating policy, of means tested transfer payment. But it is reasonable to assume that such a policy is impossible if efficiency is known to workers but not observed if the worker does not work. Then workers with low efficiency prefer avoid work altogether. Under such moral hazard the policy in the model is indeed optimal.

The locations of the US and of Europe along the curve in Figure 2 point at their optimal unemployment compensation. We can use equation (17) to calculate their actual v, namely their actual unemployment compensation, according to our model. Then we compare the optimal with the actual. The optimal v for the US should be .619. Its actual v that fits the US wage ratio of 1.9 is .383. The optimal v for Europe should be .633. But the wage ratio in Europe is 1.4 according to Brunello, Comi, and Lucifora (2000), and that fits $v = .943$. We therefore conclude that according to this simulation unemployment compensation in the US is significantly below the optimal, while in Europe it is significantly above the optimal. This shows that the different supplies of skill are far from being the only source of difference between Europe and the US. Hence, there are also very different social choices made on the two sides of the Atlantic.

The calculation of optimal social policies in this subsection should of course be taken with a grain of salt, as our model is highly stylized. The main role of this calculation is to examine whether the policy differences between Europe and the US can also be explained by the model, namely, by the difference in optimal policies given the different supplies of skilled and unskilled workers. The conclusion we reach is that the different policies cannot be explained by different labor supplies and must therefore be explained by factors outside of the model, like different social preferences.

3. Discussion

3.1. Effective Labor Supplies

We have shown above that in this model labor regulation of unemployment benefits, can lower the wage ratio between skilled and unskilled. Hence, even if Europe has relatively less skilled workers than the US, as shown in Section 2, it might still have higher wage inequality due to its labor regulation. Note though, that the rate of unemployment for skilled v/I, is lower than the rate of unemployment for unskilled v. Hence, one can say that the lower wage ratio in Europe is a result of higher effective supply of skilled workers. To clarify this point note that equations (15) and (16) imply that the ratio of employed numbers of workers in the two sectors is:

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

Hence, if in one country unemployment compensation v is higher and the wage ratio I is lower, it means that the employed number of skilled relative to employed number of unskilled is higher as well. This holds even if the overall supply of skilled relative to unskilled, L_s/L_n, is lower. Does this mean that the ratio of employments of skilled to unskilled in Europe is higher than in the US? Probably not, but it is much larger than the ratio of supplies, since unemployment is much higher among the low-skilled.

3.2. Comparison to Directed Technical Change

At this point we would like to compare our approach and results to an alternative literature, which also relates technical progress to supplies and prices of factors of production. This literature was originally called 'induced innovations', and was pioneered by Kennedy (1964), Samuelson (1965), Nelson and Phelps (1966) and others. A recent extension of this literature, called 'directed technical change,' has been developed by Acemoglu and coauthors in a number of papers, among them Acemoglu (1998), Acemoglu and Zilibotti (2001), and Acemoglu (2003). When applied to our topic of skilled vs. unskilled labor, this literature can be described by use of the following production function:

$$Y = F[A_s L_s, A_n L_n].$$

A_s and A_n are the productivities of skilled and unskilled labor respectively. Technical change increases these productivities. While the original literature from the 1960s just imposed a constraint on the two types of technical change, the directed technical change literature explicitly adds innovations and their markets, following Romer (1990).

But however innovation is modeled, it is clear that this production function implies that technical progress for skilled labor is relatively higher if this factor is relatively more abundant and if its price is lower. Hence, the skilled-bias of technical change is inversely related to the skill premium.[12] This prediction is opposite to ours. Thus our model and the induced innovation literature have conflicting predictions on the relationship between relative wages and technical change. The comparison between Europe and the US is therefore an example that can be used to distinguish between the two models.[13]

The intuitive explanation for the difference between the results of the two approaches is their different modeling of the relationship between labor and capital. While in our model technical change both replaces skill, in intermediates $[0, f]$, and complements it, in intermediates $(f, 1]$, in the directed technical change model capital

[12] This inverse relationship is mitigated by technical change itself that increases the skill premium. But when two countries are compared, as in Acemoglu and Zilibotti (2001), this inverse relationship remains and technical change is skill-biased in the country that has a lower skill premium. This result holds even if the Acemoglu and Zilibotti analysis is applied with some necessary changes to the US and Europe instead of the North and South.

[13] We of course do not criticize here Acemoglu and Zilibotti (2001), which focuses on differences between the North and the South. Our claim is that to understand the differences between Europe and the US we need a different approach.

only complements it.[14] This is the reason why the two approaches have opposite predictions with respect to technical progress and wages.

3.3. Comparison to Factors' Substitution

Another relevant comparison of our model could be to the standard neoclassical model of substitution between labor and capital. Even in a model with a fixed technology, changes in labor regulation could lead to substitution of labor by capital in the skilled and unskilled sectors. But such a model misses two important points. One is of course the changes in technology across countries, which are the main focus of this paper. According to our model not only capital replaces labor, but it also changes the production function at the same time. The second point is that the neoclassical model with fixed technology has different predictions with respect to changes in the amounts of capital. One way to see it is to assume a similar model to ours, except that f_n and f_s are not endogenous, but fixed technical parameters. It can be shown that the equilibrium is different but equations (18) and (19) hold nonetheless. Hence, both in the neoclassical model and in ours the ratio between the amounts of capital in the two sectors is:

(22) $$\frac{K_s}{K_n} = \frac{\alpha}{(1-\alpha)} \frac{f_s}{f_n}.$$

Hence, according to the neoclassical model this ratio is the same for all countries, while in our model, where technology is endogenous, this ratio differs significantly between countries and is higher if labor regulation is lower. Section 5 confronts these predictions with the facts.

[14] Interestingly, Acemoglu and Zilibotti (2001) have substitution between factors, but between skilled and unskilled workers in each intermediate good, but not between capital and labor.

4. Extensions

In this section we investigate other types of labor regulation. In order to do so in a meaningful way we need to modify some assumptions of the basic model.

4.1 Minimum wage laws

This sub-section shows that a binding minimum wage floor has a similar effect as the unemployment compensation in the benchmark case. 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.[15] 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:

$$w_n = gw_s. \tag{23}$$

The parameter *g* measures the degree of labor market regulation.

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:

$$ep_n(i) < w_n.$$

[15] The assumption of partial monitoring is added here because otherwise no one gains from the minimum wage, as shown below, so it cannot be justified.

Hence, the upper bound for firing unskilled workers is $E_n(i)$, which is equal to:

$$E_n(i) = \frac{w_n}{p_n(i)}.$$

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:

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

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. As shown in the appendix the technology frontier in the unskilled sector is described by:

(25) $$\frac{R}{1-f_n} = xw_n,$$

where x is determined by m in the following way:

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

In a similar way to the benchmark model we can now derive the demands for the intermediate goods, equate them with the supply prices and get the same "goods market equilibrium condition" (9), as in Section 2. Given that the ratio between the unskilled and skilled wages is g due to wage compression, we get from (24) and (25):

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

Together (9) and (26) determine technology adoption and wages. Clearly a rise 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.

A welfare analysis similar to that in Section 2 can show that despite the negative effects of minimum wages on some, it raises income for others and as a result the optimal degree of such regulation is not necessarily zero.[16]

4.2 Firing Costs

This extension examines another type of labor market regulation, firing costs. 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. Again, we do not explicitly add a system of unemployment compensation, but adding it leaves the model unchanged if the compensation is lower than the wage rate.

[16] Such a welfare analysis requires adding to the model some system of unemployment payments, since utility is logarithmic. If the unemployment compensation is vw_n, where $v < 1$, it does not affect workers incentives to work and therefore it does not affect the equilibrium.

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:

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

The firing threshold in the unskilled sector is similar.

It follows from (27) 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 (27) we get:

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

and:

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

Hence, increasing the firing costs raises the price, obviously, and reduces E, namely they deter firing. 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:

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

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.

To complete the analysis we get the equilibrium conditions in the two labor markets by equating supply and demand in efficiency units. In the Skilled sector we get:

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

The equilibrium condition in the market for unskilled labor is similar. From the two equilibrium conditions we derive the following labor market equilibrium condition:

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

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. Namely, higher regulation leads to more unskilled technical change and less skilled technical change.[17]

[17] If unemployment compensation is lower than both skilled and unskilled wage, people always prefer to work and the compensation does not affect the incentives and the equilibrium.

4.3 Aversion to Inequality

Thus far we have shown how various labor market regulations indirectly determine a level of wage inequality *I* lower than the unconstrained labor market would generate. Often limiting wage inequality is a direct objective of labor unions and governments, especially in Europe.[18] More precisely unions (and governments) are willing to incur the efficiency costs of adopting policies explicitly targeted to limit wage inequality. A very simple way to capture this would be to impose a constraint on *I*. [19] While we do not develop this extension further the intuition is clear: in our previous analysis, the effects of various forms of regulation affected the equilibrium by means of distorting the free-market determination of *I*. Obviously one can get the same qualitative results by imposing an exogenous upper bound on wage inequality.

5. Empirical Implications

This Section describes various facts and empirical results that support elements of the story we tell in our model. The empirical evidence is divided to three main areas: evidence on differences in labor market regulation between Europe and the US, evidence on differences in wage inequality, and evidence on differences in technology adoption in different ranges of the skill distribution.

5.1. Differences in Labor Market Regulation

Up to the mid seventies unemployment was lower in Europe than in the US and Europeans were working longer hours. After that everything changed: unemployment

[18] For a discussion of Europeans' aversion to inequality and unions' polices to limit wage inequality it see Alesina and Glaeser (2004), Alesina, Di Tella and Mc Culloch (2004) and Blau and Khan (2002).

[19] More generally one could extend the model to a case in which wage policy is set by a monopoly union which is willing to incur the costs of unemployment (especially in the unemployed are not union members) in order to obtain less inequality for those who work.

grew 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. Figures 3 and 4 highlight these patterns.

What happened? As for unemployment, a fairly accepted view goes as follows. 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 (often in consultations with unions) continued with the policies that started in the late sixties, of introducing 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.[20] As convincingly shown by Blanchard and Wolfers (2000), the interaction of this kind of labor institutions and those macroeconomic shocks generated persistent unemployment.[21]

Lets' now turn to the decline in work hours per person in Europe, a topic that has recently attracted much attention, given its remarkable magnitude. Alesina, Glaeser and Sacerdote (2005) argue that the most important explanation for this decline is labor regulation and collective union agreements including pension regulations. A good portion in the lower work hours per person in Europe versus the US is due to lower participation in the labor force, especially amongst the very young and the very old.[22] Regulations about required holiday, overtime, lower work week hours, have done the rest. European

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

[21] Subsequent work by Bertola Blau and Kahn (2002) confirms these results.

[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)).

unions argued that work sharing with the same wage (thus increasing real wage per hour) was a way of redistributing a fixed amount of work hours amongst more people.

5.2. Differences in Wage Inequality

In the eighties and the nineties we observed not only differences in unemployment between the US and Europe but also differences in wage gaps. In these years the US experienced a significant increase in the wage gap between skilled and unskilled.[23] The wage dispersion in the US became much higher than in Europe. Table 1, reproduced from Blau and Khan (1996, 2002) shows the increase in wage dispersion in the US relative to Europe. In the eighties and nineties the ratio of wages in the 50-10 deciles increased by 13 per cent for men and by 18.6 per cent for women in the US. In Europe it increased only by 4 and 3 per cent respectively. In France and Germany it actually declined. In addition note how the difference in the wage dispersion between the US and Europe is much more pronounced at the bottom end of the wage scale. Namely, the US-Europe difference is much larger in the 50-10 ratios than in the 90-50 ones. For men in the 1994-1998 period for instance the ratio 50 to 10 is 2.21 in the US versus 1.6 in Europe while in the same years the 90-50 ratio is 2.13 in the US and 1.85 in Europe (2.06 in France). At the beginning of the period this difference is even more pronounced. Note that union policies are more likely to affect wage dispersion in the bottom half rather than in the top half of the wage distribution, and in fact Blau and Kahn (2002) conclude that union policies and labor market regulation are critical in explaining the difference in wage dispersion in the two sides of the Atlantic, after controlling for many other factors which may affect this difference.[24]

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[23] See Katz and Murphy (1992) for early work on relative supply of skilled versus unskilled labor.
[24] See also Gottschalk and Smeeding (1997) for a discussion of wage dispersion in OECD countries.

Actually, stronger unions in Europe not only reduced the wage gap in Europe, at the time that it increased in the US, they even managed to maintain a relatively steady growth of real wages. Men's real wages declined in the US from 1979 till the end of the century, while wages increased substantially in Europe. Women's salaries increased in the US but less than in Europe.[25]

5.3. Differences in Technology

The labor market developments have been accompanied by an increase in the capital labor ratio in Europe. As already pointed out by Blanchard (1997), after the shocks of the seventies European firms shifted to labor saving technologies which led to an increase in the capital labor ratio and after a period of adjustment, to higher profits. He shows that from 1980 to the late nineties capital labor ratios have been steadily and sharply increasing in Continental Europe, while they have been quite stable in Anglo-Saxon economies, as also shown in Figure 5. Along similar lines, Caballero and Hammur ((1998) report a positive correlation between the capital labor ratio and the degree of labor protection in OECD countries.

We are not aware of any systematic study on whether technical progress has indeed displaced low skilled workers relative to high skilled workers in Europe. We have assembled some casual evidence that is consistent with the hypothesis that capital has substituted for low skill work. We first present some data assembled by Comin and Hobijn (2004). Their 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, three of the largest Continental European countries with highly regulated labor markets. For

[25] See Blau and Kahn (2002).

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 6 and 7 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 than in the US.

Interestingly, another technology that presents a sharp difference in adoption between Europe and the US is railway electrification. Clearly, there are many factors that affect the decision to electrify railways, like density of transportation, or topography, but one is also wages, since electrified railways are capital intensive, while diesel locomotives require more labor, and mainly more unskilled labor. Since there are many US lines that have very dense transportation, and they are mostly in the Mid-West, which is fairly flat and can afford straight rail lines, it seems that electrification could be beneficial in the US. Interestingly, the US had more electrified rails in the past, 3,000 thousand route miles in the 1930s, while now it went down to less than 1,000 route miles. Less than a percent of US railways is electrified, and only 47 locomotives out of more than 20 thousand are electric. In France, Italy and Germany on the contrary 45% of the locomotives are electric, and the percentage of electrified rail is even higher.[26]

Next we present data on capital in the skilled and unskilled sectors in the US and in our three representative European countries France, Italy and Germany. The data for the European countries are from the OECD, while the data for the US is from the BEA. The division of sectors to skilled and unskilled is done according to share of skilled

[26] See World Bank Railways Database (2006).

professions, where a sector with more than 50% skilled is defined as skilled. We then sum up net capital stocks in both types of sectors to get K_s and K_n. Figure 8 plots the ratios between the two amounts of capital in the various countries. This is the ratio which is described in equation (22) and it depends on the ratio between f_s and f_n. The figure implies that this ratio has been higher in the US than in Europe, which supports the predictions of our model.

The graphs in Figure 8 imply that the ratio between f_s and f_n has been higher in the US than in Europe. We next examine whether we can trace differences between the two regions with respect to f_s and f_n separately. From equation (18) we get that:

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

Hence, comparing the capital to output ratios across countries enables to compare the degree of skill-biased technical progress, assuming the two regions face similar interest rates. Similarly from equation (19) we get:

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

This enables to compare unskilled-biased technical change between the two regions. Figure 9 presents the ratios of capital to output in the skilled sectors in our four countries. It shows that technical progress in these sectors was higher in the US than in the European countries. Figure 10 presents the ratios of capital to output in the unskilled sectors and it clearly shows that unskilled biased technical progress in the US is declining significantly and it is below the European countries in recent decades.

An additional interesting and suggestive evidence to our model, which builds on data within the US, is Lewis (2005). Using plant level data, Lewis 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. This suggests that availability and relative costs of low skill workers affect firms' technological choices. The same author even finds evidence of de-adoption of automation technologies in cities that receive an especially large influx of immigrants.

5.4. Unemployment and Public employment

It is important to note that the extent of unemployment in European countries would have been even greater without the use of public employment to alleviate unemployment at relatively low skilled level. Evidence on this point is provided by Edin and Topel (1997), Bjorklund and Freeman (1997) and Kahn (1998a) for Norway and Sweden (see however Kahn (2000b) for some discussion of robustness); by Blau and Kahn (2000b) for Germany and by Alesina, Danninger and Rostagno (2001) for Italy. Our model can easily account for this by redefining the unemployment subsidy as the wage of a public job. Then a worker would accept a job in the private sector only at a wage higher than the public sector job. The "unemployed" in our model would then be redefined as public employees. Another relevant factor is that when low skilled jobs are scarce, the opportunity costs of staying in school declines and young people stay in school longer. In Italy the average age of college graduation is 27.8.[27]

5.4. Job Creation in Private and Public Sectors

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. This is precisely what Pissarides (2006) finds. He argues that the Lisbon target for job creation in Europe will not be achieved because of sluggish creation of jobs in Europe in the labor intensive low

[27] See Dornbusch, Gentilini and Giavazzi (2000) on this issue.

skilled service sectors, which is where most job creation has occurred in the US and UK. Pissarides (2006) concludes that European countries have been successful at creating jobs in the "knowledge sectors"……but have been unsuccessful at creating them in labor intensive….sectors" which is exactly one of the implications of our model.[28] This 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)). Job creation in Europe would have been even lower and unemployment higher without the use of public employment to alleviate unemployment at relatively low skilled level. Often public job programs for "community service jobs" (as above) such as cleaning parks and roads assistance to elderly living at home alone are staffed by hiring individuals that would not be hired by the private sector. Evidence for that is also provided by Edin and Topel (1997), Bjorklund and Freeman (1997) and Kahn (1998a) for Norway and Sweden (see however Kahn (2000b) for some discussion of robustness); by Blau and Kahn (2000b) for Germany and by Alesina, Danninger and Rostagno (2001) for Southern Italy. Our model can easily account for this by redefining the unemployment subsidy as the wage of a public job. Then a worker accepts a job in the private sector only at a wage higher than the public sector job. The "unemployed" in our model would then be redefined as public employees. Another relevant factor is that when low skilled jobs are scarce, the opportunity costs of staying in school declines and young people stay in school longer. In Italy the average age of college graduation is 27.8.[29]

6. Conclusions

[28] See Table 4 of Pissarides (2006) for evidence.
[29] See Dornbusch, Gentilini and Giavazzi (2000) on this issue.

After the seventies' the performance of labor markets in Europe and in the US departed significantly in many aspects. In the US labor markets remained relatively unregulated and some elements were even further deregulated. The US experienced a sharp increase in wage inequality, a stagnation of real wages for low skilled work, low unemployment and stability of labor force utilization in terms of hours per person in working age. 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. These policies fit with the general European aversion to excessive inequality. 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 affected technical progress and led to differences between the two regions. We show that 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. Our model therefore looks at the patterns of technical progress and their skill bias not only as endogenous, but also as affected by labor market policies and by wage gaps in various regions.

In summary our model suggests that the nature of technical progress is influenced by wages and by labor market policies. Obviously various exogenous developments in science and technology, like the invention of computers, play an important role. But the speed of adoption and of adjustment to new technologies depends on labor market regulations and policies. More empirical work is needed to assess more directly the effects suggested by the paper. As for welfare, while we show that some insurance to labor outcomes raises welfare, one should investigate more thoroughly the comparative role of different types of welfare and labor protection laws.

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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:

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

Using (6) and $\int_0^{f_s} \log(1-i)di = -(1-f_s)\log(1-f_s) - f_s$ we get that 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:

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

and:

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

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.

<u>Derivation of the Labor Market Equilibrium Conditions</u>

The supply of employed skilled labor in efficiency units is equal according to (14) to:

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

The supply of unskilled labor is equal according to (13) to:

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

The demand for skilled labor is equal to:

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

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 (15) and (16).

<u>Derivation of Expected Utilities</u>

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 $\log j$. We therefore treat log$j$ as utility from here on. Expected utility 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 (23). Ex-ante expected utility of skilled is calculated similarly.

<u>Derivation of Technology Frontier in the Unskilled Sector for Minimum Wage</u>

The technological frontier at the unskilled sector is determined at the point where the unit cost of machinery is equal to the average unit cost of producing by labor:

(A.5) $$\frac{R}{1-f_n}=\frac{m\int_{E_n(i)}^1 w_n de+(1-m)\int_0^1 w_n de}{m\int_{E_b(i)}^1 ede+(1-m)\int_0^1 ede}=2\frac{w_n-m\frac{w_n^2}{p_n(i)}}{1-m\frac{w_n^2}{p_n^2(i)}}.$$

To derive the equilibrium price of an unskilled intermediate good which is produced labor, note that profits are driven to zero by free entry. Hence price equals average cost and it follows from (A.5) that:

(A.6) $$p_n(i)=2\frac{w_n-m\frac{w_n^2}{p_n(i)}}{1-m\frac{w_n^2}{p_n^2(i)}}.$$

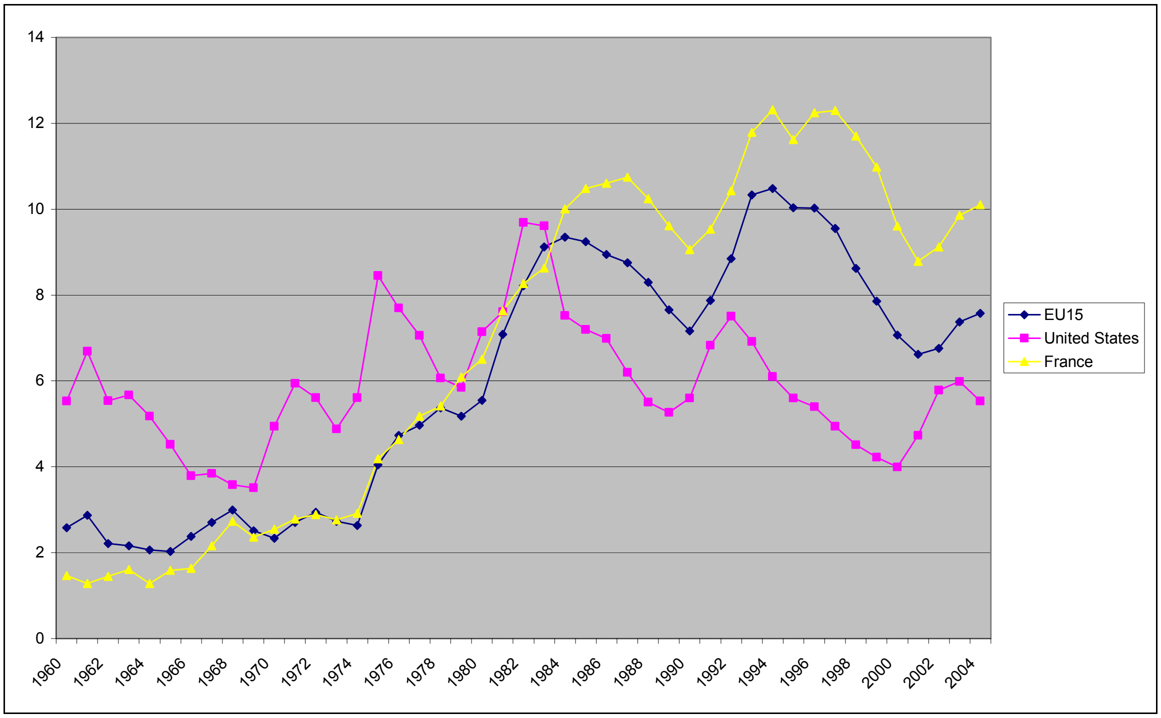
Solving (A.6) shows that the price is equal to: $p_n(i)=p_n=xw_n$ where x is:

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

This proves equation (25).

Figure 3

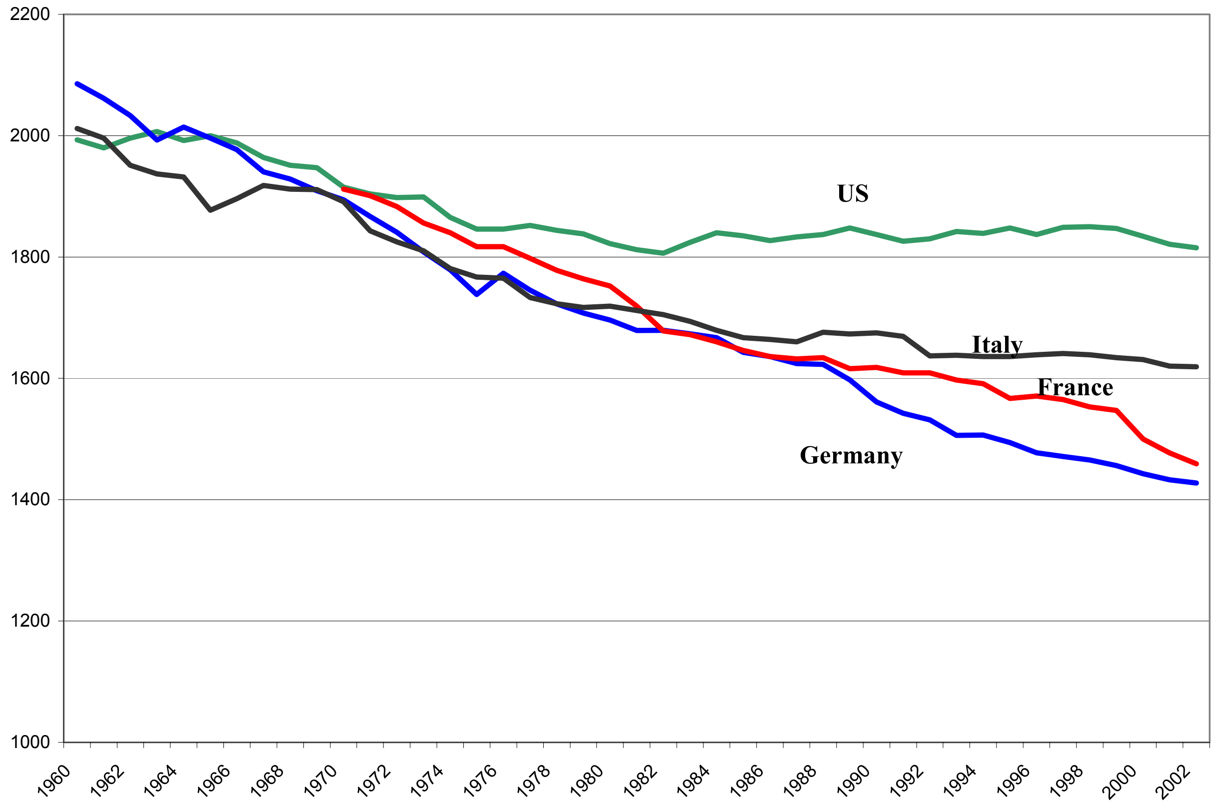
Unemployment Rate, 1960-2004 (%)



Source: OECD.

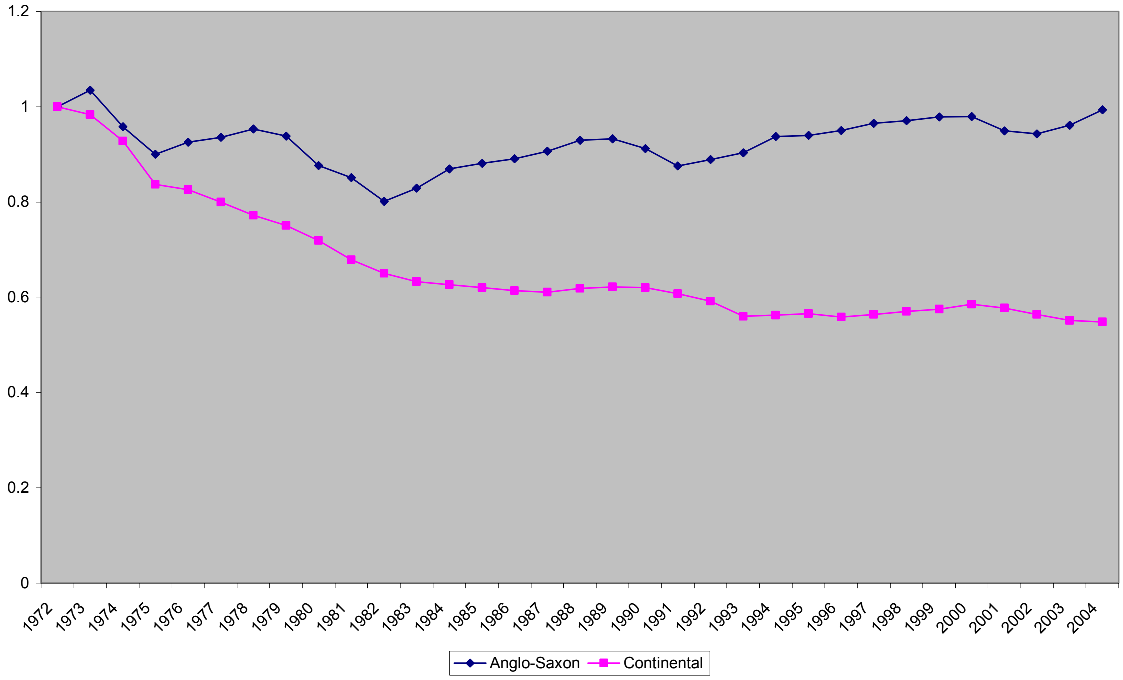
Note: EU15 corresponds to an unweighted average. Before 1977, not all countries from the EU15 are in the sample (as many as seven countries missing in some years); data from the Netherlands are available only until 2002.

Figure 4
Annual Hours Worked Over Time



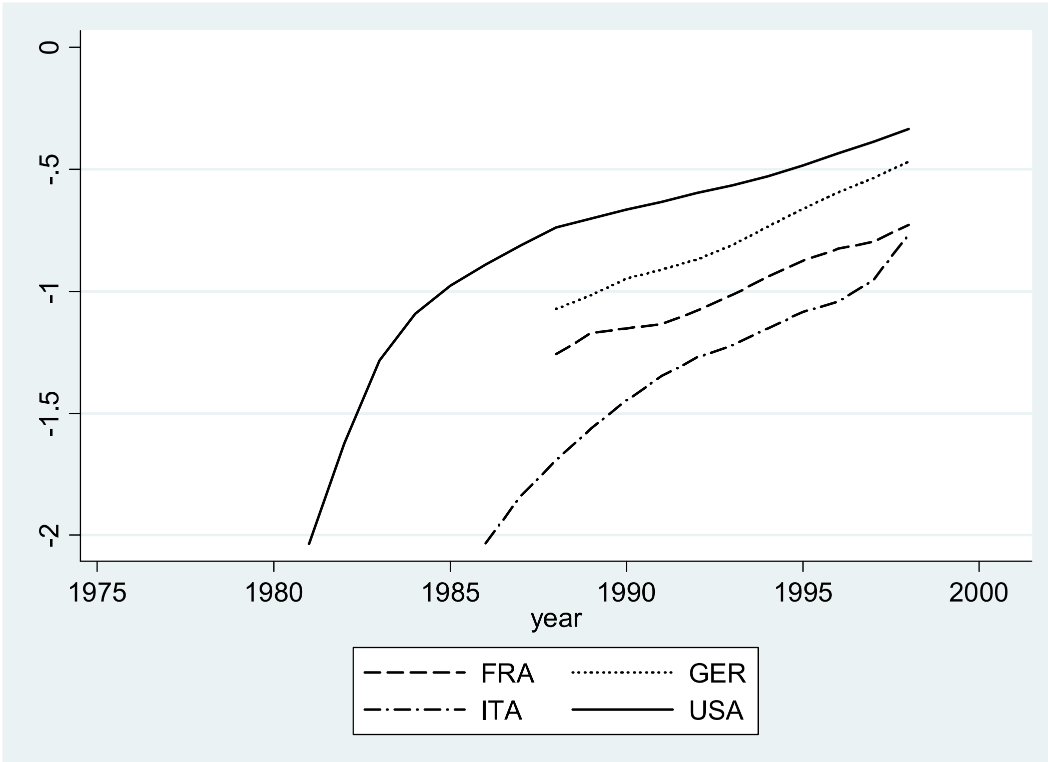
Source: OECD data. Annual hours per employed person. Annual hours are equivalent to 52*usual weekly hours minus holidays, vacations, sick leave. Reproduced from Alesina Glaeser and Sacerdote (2005)

Figure 5
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.

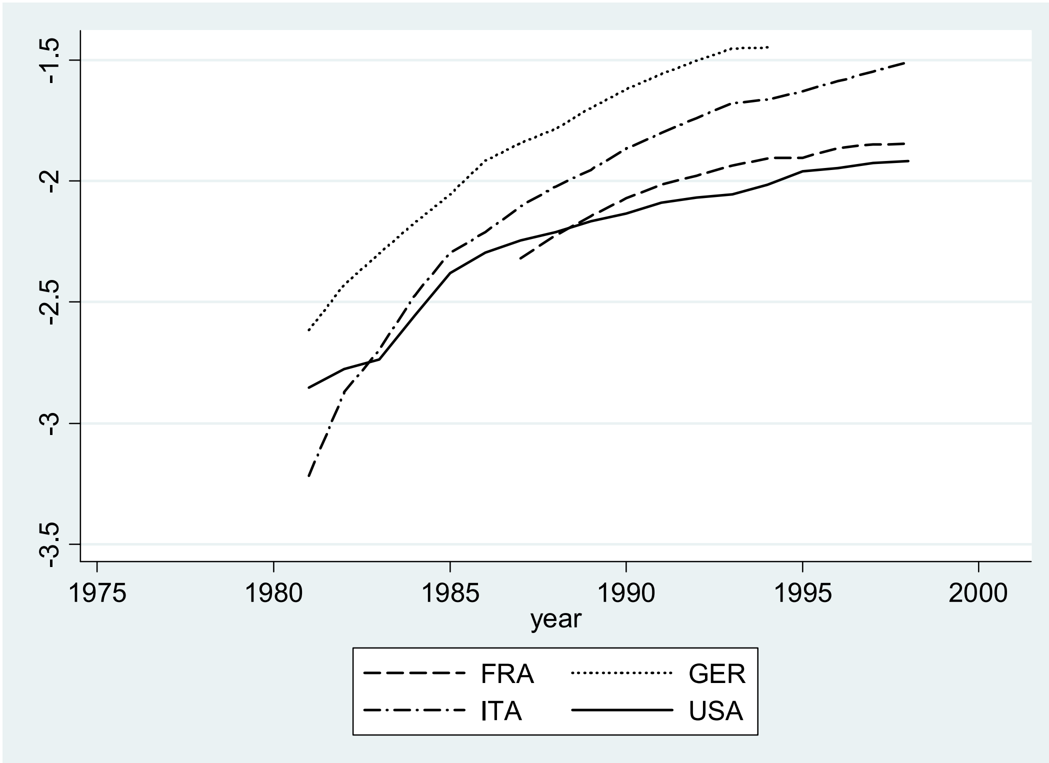
Figure 6
Personal Computers per capita
(in logs)



Source: HCCTA.

Figure 7

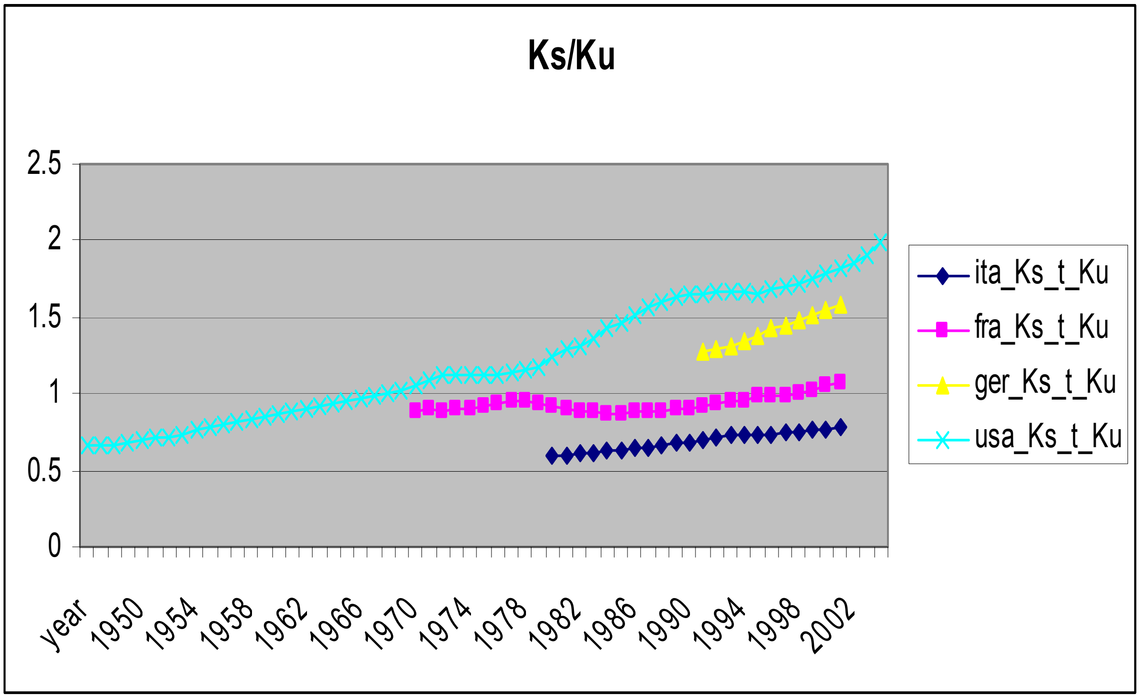
Industrial Robots as share of GDP
(in logs)



Source: HCCTA.

Figure 8

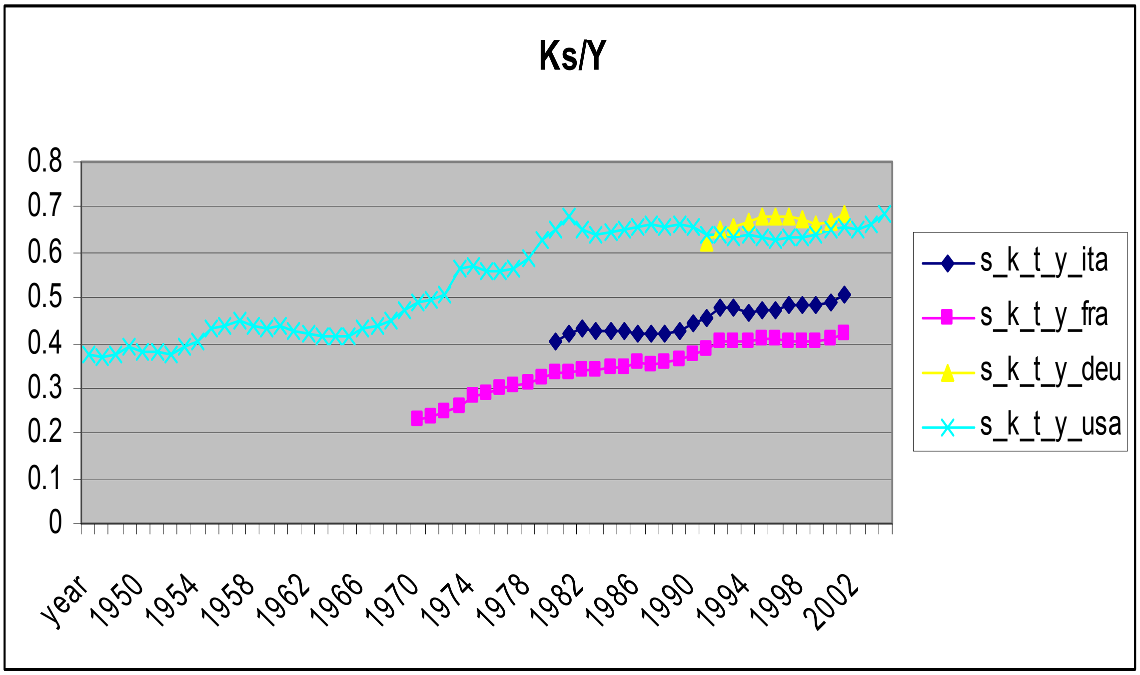
Capital Ratios between High Skilled and Low Skilled Sectors in Europe and the US



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

Figure 9

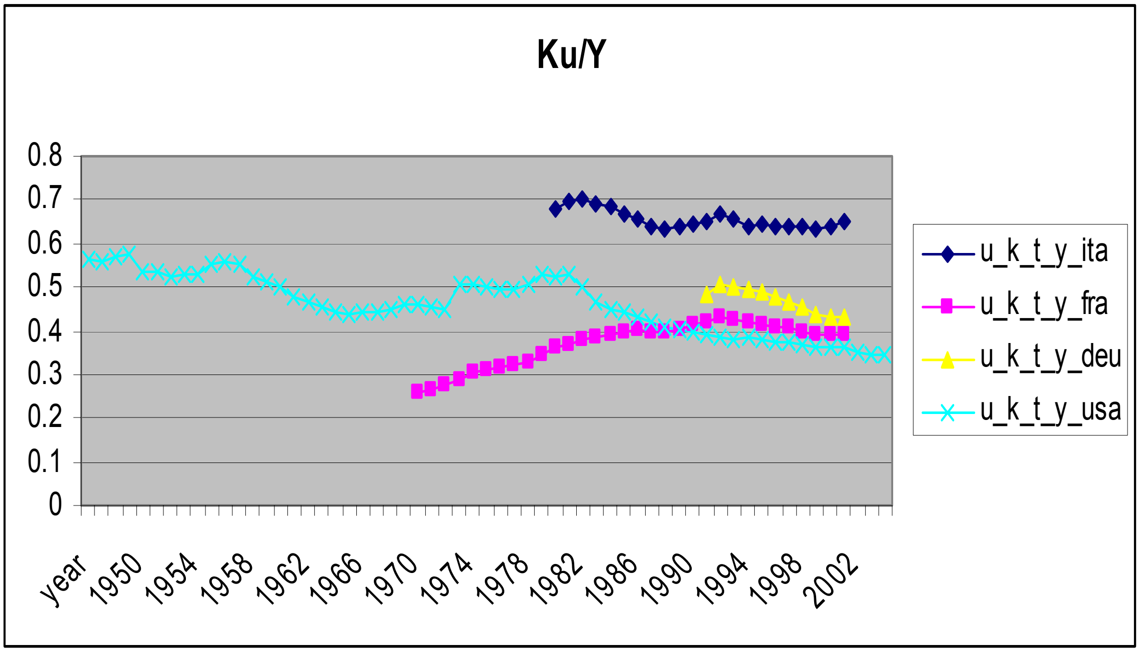
Ratio of Capital in Skilled Sectors to Output in US, France, Italy, and Germany



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

Figure 10

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.

Table 1
50-10 and 90-50 Weekly Earnings Ratios, Full-Time Workers

Country	50-10				90-50			
	1979-1981	1989-1990	1994-1998	% Change	1979-1981	1989-1990	1994-1998	% Change
A. Men								
United States	1.95	2.14	2.21	13.00	1.82	2.05	2.13	16.70
France (net earnings)	1.66	1.63	1.60	-3.90	2.04	2.14	2.06	0.80
Germany (West)	1.52	1.45	1.46	-4.30	1.68	1.71	1.80	7.20
Europe*								
Current sample	1.54	1.51	1.60	4.07	1.70	1.73	1.85	9.11
1979-1981 sample	1.54	1.56	1.57	1.95	1.70	1.77	1.82	6.82
B. Women								
United States	1.65	1.87	1.96	18.60	1.76	2.01	2.13	20.80
France (net earnings)	1.59	1.65	1.56	-2.00	1.70	1.71	1.71	0.40
Germany (West)	1.79	1.75	1.60	-10.60	1.73	1.59	1.64	-5.20
Europe*								
Current sample	1.58	1.57	1.62	3.07	1.60	1.62	1.71	6.85
1979-1981 sample	1.58	1.60	1.59	0.63	1.60	1.66	1.63	2.00

* Europe is defined as:
1979-81 - Austria, Finland, France, Germany, Sweden, United Kingdom.
1989-90 - Same as 1979-81, plus Belgium, Italy, Netherlands, Switzerland.
1994-98 - Same as 1989-90, plus Ireland, Spain. (In 1994-98, Austria and Belgium have data for the 50-10 ratio only.)