

# Technology and Labor Regulations: Theory and Evidence

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## Abstract

This paper shows that different labor market policies can lead to differences in technology across sectors in a model of labor saving technologies. Labor market regulations reduce the skill premium and as a result, if technologies are labor saving, countries with more stringent labor regulation, which are binding for low skilled workers, become less technologically advanced in their high skill sectors, but more technologically advanced in their low skill sectors. We then present data on capital output ratios, on estimated productivity levels and on patent creation, which tends to support the predictions of our model.

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# Technology and Labor Regulations: Theory and Evidence

## 1. Introduction

Countries differ in the technologies they use for production. The most studied differences are between rich and poor countries, but even rich countries differ significantly, which is the topic of our paper. We argue that labor market regulations have a significant effect on technology adoption. More labor regulation biases technology toward low skill sectors, while less labor regulation biases technology toward high skill sectors. We present a model, which has this implication and empirical evidence that supports it.

Our theoretical argument relies on the assumption that many technologies are ‘labor cost saving,’ which reduce the amount of labor in production and replace it by machinery, by automation, and in general by capital. Hence, adoption of these technologies depends on the prices of capital and of labor. High wages induces mechanization, while low wages deter it. We connect wages to labor regulation through the changes in the relative supplies of high and low skills. Government regulations of the labor market, like firing costs and other limitations on layoffs, reduce competition in the labor market, but also reduce the supply of low skill workers relative to the supply of high skilled. As a result, the low skill wage rises and the high skill wage declines. This leads to more mechanization in the low skill sector and to less mechanization in the high skill sector.

We present the main claim of the paper by a model of ‘labor-cost saving technologies’ with two sectors, high and low skilled. We also assume that workers differ by personal efficiencies but also by education, which increases their personal efficiency. This heterogeneity enables us to analyze the labor market and its reaction to regulation. We model the labor regulation as firing costs.<sup>1</sup> When firing costs rise, less workers are fired. Since high skilled workers have higher efficiency, employers fire fewer of them relative to low skilled workers. As a result, the reduction in the supply of high skilled is smaller than the reduction of the supply of high skilled. Hence, the skill premium declines and higher firing costs raise the cost of low skill labor and reduce the cost of high skill labor. Therefore, in countries with

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<sup>1</sup> In a previous version of this paper we derived similar results using other forms of labor regulation. More details are available from the authors.

more stringent labor regulation, technology adoption is low skill biased, while in countries with less stringent labor regulation, technology adoption is high skill biased.

The model has additional empirically testable implications. One is that labor regulation reduces the ratio between capital in the high skill sector and capital in the low skill sector, due to mechanization. The second result is that labor regulation should reduce productivity in the high skill sector, but its effect on low skill productivity is unclear due to two opposing effects, lower average efficiency of labor and higher mechanization. The paper also discusses, for the sake of comparison, a standard model, which is identical to our model except for technology adoption. We show that in this standard model firing costs have different empirical implications than in our model. We then use test the opposite predictions of the two models, and the results broadly support ours.

Our empirical tests use three measures of labor market regulation as explanatory variables. These are Employment Protection Legislation, Union Density, which is the share of union membership, and Union Coverage, which is the share of workers covered by collective bargaining. The use of Employment protection legislation follows directly from our model. Labor unions should have a similar effect on technologies since much of union activity is to protect workers from being fired. The second reason is that unions promote various forms of labor laws, which increase employment protection legislation. We then test the effects of these three variables on three dependent variables, according to the implications of the model. One is the ratio between capital in the high skill and capital in the low skill sectors. The second variable is productivity in the high and low skill sectors, which we calculate following Caselli and Coleman (2006). The third variable is patent data by sectors. The justification is that the types of technologies adopted by a country should be correlated with the type of technologies it develops. The results of all the empirical tests fit the predictions of our model.

This paper belongs to several lines of research. The first is on technology adoption, trying to understand why it differs across countries. An early contribution to this literature is Parente and Prescott (1994), who point at adjustment costs in technology adoption. Other papers explain non-adoption by low levels of human capital, or by geographical bias of technologies.<sup>2</sup> Our model belongs to a specific branch in this literature, called ‘labor costs induced innovations,’ which is an extension of a much earlier literature on ‘directed technical change.’ Our model follows Champnowne (1961) and Zeira (1998), who modeled new technologies as machines that replace workers. Some recent papers that use the idea

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<sup>2</sup> See Galor and Moav (2004) and Zeira (2009) for the effect of low human capital on technology adoption and see Sachs (2000) for the effect of geographical bias, especially in agricultural and medical technologies, on development.

of labor saving technical change are Hellwig and Irmen (2001), Saint-Paul (2006), Zuleta (2008), and Peretto and Seater (2013). See also Acemoglu (2010) for a summary of this literature.<sup>3</sup>

This paper is also relevant to the research on the recent decline of the share of labor, since replacing workers by machines reduces the share of labor and increases the share of capital in output. Autor, Levy and Murnane (2003) claim that the process of mechanization happens mainly for routine jobs, which are easier to automate. Acemoglu and Autor (2011) argue that most routine jobs and most automation are in middle skill jobs. Karabarbounis and Neiman (2014) and Eden and Gaggl (2016) show that half of the decline in the share of labor is in information and communication technologies (ICT). This paper draws a subtler picture and shows that labor deregulation causes the decline of the share of low skill labor, while it raises the share of high skill labor, due to differences in technology adoption.

A third line of research this paper touches, is on the relation between technical change and the skill premium. Much of this literature claims that skill-biased technical change raises the skill premium.<sup>4</sup> We suggest instead that the rise of the skill premium and skill-biased technical change in the US could have been the result of a third development, namely deregulation of labor markets. This paper, therefore, raises the possibility of some reverse causality, where higher wage inequality induces skill biased technical change and not the other way around.<sup>5</sup>

Another related literature is on the economic differences between Europe and the US. While US labor markets have been deregulated and labor unions significantly weakened since the 1980s, most West European countries have kept relatively high levels of labor regulation. According to many economists, these different policies led to the observed differences in unemployment rates between the US and Western Europe and to differences in the skill premium.<sup>6</sup> The growing differences in labor regulation were documented in many studies, among them Nickell (1997) and Nickell and Layard (1999).<sup>7</sup> For example, employers can fire workers in France, Germany and Sweden only with advance

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<sup>3</sup> Applications of this approach to understanding economic fluctuations are Blanchard (1997), Caballero and Hammour (1998) and Beaudry and Collard (2002).

<sup>4</sup> Much of this literature focuses on the US. 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), Berman, Bound and Machin (1998), and Acemoglu (1998, 2003b).

<sup>5</sup> Koeniger and Leonardi (2007) also raise this possibility.

<sup>6</sup> The effect of such labor institutions on persistent unemployment in the presence of macroeconomic shocks is analyzed by Lazear (1990), Blanchard and Wolfers (2000), and Blanchard, Cohen and Nouveau (2005). See also Freeman and Katz (2007), Ljungqvist and Sargent (1996), Blau and Kahn (1996 a, 2002), and Saint-Paul (2004). For the effect of regulation on the skill premium see Katz and Murphy (1992), Blau and Khan (1996 b, 2002) and Gottschalk and Smeeding (1997).

<sup>7</sup> We do not study here what led to these differences between the US and Europe. Discussions on differences in culture and in attitudes toward welfare policies appear in Alesina and Glaeser (2004) and in Alesina et al. (2014).

notices of 7 to 8 months, while in the US a much shorter time is required. Studies have shown that such differences in labor regulation also led to differences in hours worked.<sup>8</sup> Other studies have shown that differences in labor regulation have affected also sector distributions.<sup>9</sup> O’Mahoney and Van Ark (2003) argue that labor market regulation led to substitution of labor by capital in some sectors, but do not relate it to technology, as this paper does.<sup>10</sup> Acemoglu (2003a) and Koeniger and Leonardi (2007) find that labor-capital substitution has been larger than what standard production functions imply. Our paper can explain this finding, as technology choice intensifies capital-labor substitution.<sup>11</sup>

The paper is organized as follows. Section 2 presents the basic model. Section 3 derives the main result on technology adoption, while Section 4 presents additional results. Section 5 describes the data and Section 6 presents some descriptive correlations. Section 7 presents the empirical analysis of the effects of labor regulation on the capital ratio, Section 8 on productivities and Section 9 on patent creation. Section 10 studies the relation between labor regulation and wage dispersion and Section 11 concludes. Appendix A contains proofs and Appendix B contains additional empirical results.

## 2. A Model of Technology and Labor Regulation

Consider an economy with a single final good, used both for consumption and for investment, which serves as a numeraire. The population in the economy consists of overlapping-generations. In each generation, there is a continuum of people of size 1, who live two periods. In the first period they acquire education and work, and save all their net income. In the second period they consume and their utility is described by  $\ln(c)$ , where  $c$  is consumption in second period of life.

In their labor ability people differ both by education and by personal efficiency. Those, who do not acquire education, are called low skilled, and have a random efficiency  $e$ , which is distributed exponentially over  $[a, \infty)$ , where  $a > 0$  and the density function of efficiency is:

$$(1) \quad \exp(a - e).$$

People who acquire education have on average higher efficiencies. More precisely, their efficiency is distributed also exponentially, but over  $[b, \infty)$ , where  $b > a$ . Let  $L_N$  be the share of low skilled and  $L_S$

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<sup>8</sup> See Prescott (2004), Blanchard (2004), Alesina, Glaeser and Sacerdote (2005) and Rogerson (2007).

<sup>9</sup> See Davis and Henrekson (1997, 1999, 2005a) and Bertrand and Kramarz (2002).

<sup>10</sup> See also Beaudry and Green (2005), Davis and Henrekson (2005b), Freeman and Schettkat (2005), Autor, Kerr and Kugler (2007) and Pissarides and Ngai (2009).

<sup>11</sup> Acemoglu (2003a) and Koeniger and Leonardi (2007) offer a different explanation to labor-capital substitution through distortions to investment by labor regulation.

the share of high skilled, so that:  $L_N + L_S = 1$ . We assume that the numbers of high and low skill workers are exogenous.<sup>12</sup> We further assume that personal efficiency is not verifiable and only employers can observe it, once the worker begins his job. The order of events in the labor market is the following. An employer hires a worker and after she observes his efficiency, she decides whether to keep him employed or to fire him and incur the required firing costs. Due to this informational assumption, individual efficiency cannot be part of the labor contract, and wages depend only on whether a worker is high or low skilled, which is common knowledge. Note, that although the wage does not depend on individual efficiency, it does reflect average efficiency among the employed, as shown below. We denote the real wage of the skilled by  $w_S$  and the real wage of the unskilled by  $w_N$ .

The final good in this economy is produced by two goods, the high skilled good  $S$  and the low skilled good  $N$ , using the following CES production function:

$$(2) \quad Y = \left( S^{\frac{\theta-1}{\theta}} + N^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}.$$

The parameter  $\theta$  is the elasticity of substitution between the two goods. As shown in Section 5, empirical studies place the elasticity of substitution between high skilled and low skilled labor between 1 and 2. Following these studies, we assume that the elasticity of substitution between the two goods satisfies these bounds as well and hence:  $1 < \theta < 2$ .

The high skilled good is produced by a continuum of intermediate goods  $i \in [0,1]$ , according to the following Cobb-Douglas production function:

$$(3) \quad \ln S = \ln A + \int_0^1 \ln s(i) di,$$

where  $s(i)$  is the quantity of the high skilled intermediate good  $i$ . There are two potential technologies to produce each intermediate good. One is manual, where a unit of  $i$  is produced by 1 efficiency unit of high-skilled labor. The second technology is mechanized and one unit of  $i$  is produced by a machine of size  $k(i)$ . Capital depreciates fully within 1 period. We assume for simplicity that once producers want to adopt a mechanical technology, its invention is costless. Hence, the only cost of mechanization is the cost of purchasing the machine. Assume that this cost,  $k(i)$ , is rising with  $i$ , and to simplify the analytical solution we use the following specification:

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<sup>12</sup> We have found that the main results of the model do not change if acquisition of skill is endogenous.

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

The coefficient  $\kappa$  is positive. Note that it is related to the capital-output ratio and since time-periods in this model are quite long, around 30 years at least, the capital output ratio should be very low, below 0.1. We therefore also assume that  $\kappa$  is low as well. Production of the low skilled good is similar to that of high skilled:

$$(5) \quad \ln N = \ln A + \int_0^1 \ln n(i) di.$$

Similarly, each low-skilled intermediate good can be produced either by one efficiency unit of low-skilled labor or by a machine of size  $k(i)$ , where the function  $k$  is the same as in (4).

These technological assumptions are important for the model's results, especially the effect of wages. If wages rise, producers tend to replace labor by new machines, namely they mechanize more intermediate goods and adopt more technologies. Hence, this model is clearly within the literature of 'labor cost reducing technical change,' as in Acemoglu (2010). Our technological assumptions are highly intuitive. Many major technical breakthroughs in the history of economic growth consisted of machines that replaced human and sometimes animal labor. Weaving machines, trains, cranes, computers, radio, cinema and television, which replaced many local newspapers and theaters, are just a few examples. Note that such machines can replace low skill labor, like the electric dishwasher, or high skill labor, like GPS, which replaces human navigators.

We next turn to labor market regulations. Firms face firing costs, which are equal to the wage of the fired worker times  $h$ , where  $h < 1$ . This is a typical employment protection legislation, EPL. For simplicity, assume that these costs are payments by firms to the government. We assume for simplicity that firms are large, so that the distribution of efficiency within each firm is the same as in the overall economy. Unemployed workers receive a compensation from the government, which is equal to  $g$  times the wage of the worker, whether high or low skilled, and  $g < 1$ . The government issues a tax of rate  $t$  on all wage income to finance these compensations, minus the firing costs it collects from firms.

The economy is open to capital mobility and is small, so that the world interest rate is exogenous and constant. The total cost of capital, which is the sum of the interest rate  $r$  and the rate of depreciation, is equal to  $R = 1 + r$ . The economy trades only in the final good, and not in intermediate goods.<sup>13</sup>

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<sup>13</sup> Workers save their net income, while investment depends on technical progress. Zuleta (2015) discusses capital flows in a similar model.

We further assume that the parameters of the model satisfy the following three constraints. The first limits the extent of firing costs, to rule out more extreme cases where no workers are fired in equilibrium:

$$(6) \quad h \leq \frac{1}{1+b}.$$

The second constraint limits the labor supplies to ensure that there is a positive skill premium:

$$(7) \quad \frac{L_S}{L_N} \leq \frac{a(1+a)}{b(1+b)}.$$

The third constraint supplies upper and lower bounds for the productivity parameter  $A$ :

$$(8) \quad 2 \exp(1-\theta) < \left( \frac{A}{\kappa R} \right)^{1-\theta} < 1 + \exp(1-\theta).$$

These constraints guarantee the existence of an interior equilibrium, as shown below.

### 3. Equilibrium with Endogenous Technologies

#### 3.1 Employment and Firing

Consider a firm in a high skilled sector  $i$  that produces by labor and faces a price  $p_S(i)$  and real wage of high skill workers  $w_S$ , which is uniform across all sectors. The profit from keeping a worker of efficiency  $e$  is  $p_S(i)e - w_S$ , and the profit from firing this worker is  $-hw_S$ . Hence, the firm will hire only workers with efficiency equal or above a threshold,  $v_S(i)$ , where:

$$(9) \quad v_S(i) = \frac{w_S(1-h)}{p_S(i)}.$$

To find the price  $p_S(i)$ , note that due to free entry, the profits per worker of each firm, which are revenues minus labor costs minus firing costs, are driven to zero:

$$p_S(i) \int_{v_S(i)}^{\infty} e \exp(b-e) de - w_S \int_{v_S(i)}^{\infty} \exp(b-e) de - hw_S \int_b^{v_S(i)} \exp(b-e) de = 0.$$

In Appendix A we show how from this condition and from (9) we get:

$$(10) \quad v_S(i) \exp[v_S(i) - b] = \frac{1-h}{h}.$$

This equation determines a unique threshold of hiring for each level of regulation  $h$ . Due to constraint (6) the threshold satisfies:  $v_S > b$ , namely, some workers are fired. The threshold  $v_S(i)$  does

not depend on the sector  $i$  and hence we denote this hiring threshold from here on by  $v_S$ . As a result, prices of high skilled intermediate goods are also equal across sectors that produce with labor:  $p_S(i) = p_S = w_S(1-h)/v_S$ . The relationship between  $v_S$  and  $h$  described by (10) is negative, so that as labor regulation is liberalized, more workers are fired. As  $h$  declines toward zero,  $v_S$  rises to infinity. The intuition is that as firing costs disappear, firms fire all workers below average, but this raises the average more and further increases firing. This result should not worry us too much, as it holds only for extremely low values of  $h$ , while  $v_S$  is quite low, even as  $h$  becomes very small. One way to overcome it, is to assume that there is some lower bound for  $h$ .<sup>14</sup>

We analyze hiring in low skilled sectors in a similar way. We get that the hiring threshold in low skilled sectors is independent of the sector and is determined by the following condition:

$$(11) \quad v_N \exp(v_N - a) = \frac{1-h}{h}.$$

Similar to high skilled prices, the prices for low skilled intermediate goods are also equal across sectors,  $p_N = w_N(1-h)/v_N$ . From equations (10) and (11) it follows that the threshold  $v_N$  is lower than  $v_S$ , but  $v_N - a > v_S - b$ , which means that there is more firing in low skilled firms. As  $h$  rises, both  $v_S$  and  $v_N$  decline, but  $v_S$  declines by more. This means that higher labor regulation increases the set of high skill workers by more than the set of low skill workers.

### 3.2. Technology Adoption

Note that the price of a high-skilled good produced by labor is equal to the average cost of its labor production, as profits are driven to zero by competition. Then, production of a high skill intermediate good is mechanized, if production by labor is more expensive than by a machine, namely if:

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

Hence, all high skill intermediate goods, for which  $i \leq f_S$ , are produced by machines, where the technological frontier for high skill workers,  $f_S$ , is determined by:

$$(12) \quad 1 - f_S = \frac{\kappa R}{p_S}.$$

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<sup>14</sup> A simulation found that even for  $h = 0.01$ , the value of  $v_S$  is 5. Another way to avoid  $v$  from running to infinity is to assume that even production by labor uses some capital, for structures. In that case, operating profits are not driven to zero. We do not follow this possibility, since it complicates the solution of the model.

Similarly, all low skilled sectors with  $i \leq f_N$ , are mechanized, where:

$$(13) \quad 1 - f_N = \frac{\kappa R}{P_N}.$$

The low cost machines replace workers in the corresponding jobs, while workers in the other jobs remain at work, as machines that can replace them are too expensive. Hence, technical change substitutes labor by capital, but capital is also complementary to labor. Increasing  $f_S$  or  $f_N$  moves workers into the remaining jobs,  $[f_S, 1]$  and  $[f_N, 1]$ . There they become more productive, as they work with more machines. Consider for example an accountant, who uses a computer for calculations, which she used to do manually before. As a result, she becomes more productive.

### 3.3 Equilibrium in the Goods Markets

The supply prices of the high skilled intermediate goods are:

$$(14) \quad p_S(i) = \begin{cases} \frac{\kappa R}{1-i} & \text{if } i \leq f_S \\ p_S & \text{if } i > f_S. \end{cases}$$

On the demand side, profit maximization in the production of  $S$  yields the following first order condition, where  $P_S$  denotes the prices of the high skill final good:

$$(15) \quad p_S(i) = \frac{P_S S}{s(i)}.$$

A similar condition holds for low skill production as well, where  $P_N$  denotes the price of the low skill final good. Combining the supply price (14) and the demand price (15) with the production function (3), yields the following equilibrium prices, where the calculations for the low skill intermediate goods are similar:

$$(16) \quad P_S = \frac{\kappa R}{A} \exp(f_S) \text{ and } P_N = \frac{\kappa R}{A} \exp(f_N).$$

The proof of (16) is in Appendix A.

We next turn to the demand for the aggregate goods  $S$  and  $N$ . Profit maximization of the final good production (2) leads to the following first order conditions:

$$(17) \quad P_S = \left( \frac{Y}{S} \right)^{\frac{1}{\theta}} \text{ and } P_N = \left( \frac{Y}{N} \right)^{\frac{1}{\theta}}.$$

By substituting equation (17) in the production function (2) and using equation (16) with the supply prices, we derive the following condition, which describes the equilibrium in the goods markets:

$$(18) \quad \exp[(1-\theta)f_S] + \exp[(1-\theta)f_N] = \left(\frac{A}{\kappa R}\right)^{1-\theta}.$$

The proof of equation (18) is in Appendix A. Equation (18) defines a relationship between the two technological frontiers  $f_S$  and  $f_N$ , which is negative and convex. This equilibrium in the goods markets is described by curve **G** in Figure 1 below. The constraint (8) implies that the curve **G** passes below the point (1, 1), and that it crosses the vertical axis above 1.

### 3.4 Equilibrium in the Labor Markets

There are two labor markets in the economy, for high skilled and for low skilled. We next describe the equilibrium in each market in efficiency units of labor. Note, that the fired workers are out of the market already, so the amount of employed high skilled labor in efficiency units, denoted by  $E_S$ , is equal to:

$$E_S = L_S \int_{v_S}^{\infty} e \exp(b-e) de = L_S(1+v_S) \exp(b-v_S).$$

Applying equation (10), we get that the amount of high skilled labor is:

$$E_S = L_S(1+v_S)v_S \frac{h}{1-h}.$$

The demand for high skilled labor in efficiency units is equal to:

$$\int_{f_S}^1 s(i) di = \int_{f_S}^1 \frac{P_S S}{p_S} di = (1-f_S) \frac{P_S S}{p_S}.$$

Using equations (12), (16), and (17) we can show that the demand for high skilled labor is:

$$\frac{1-f_S}{p_S} Y P_S^{1-\theta} = \frac{(1-f_S)^2}{\kappa R} Y P_S^{1-\theta} = \frac{(1-f_S)^2}{\kappa R} Y \left(\frac{\kappa R}{A}\right)^{1-\theta} \exp[(1-\theta)f_S].$$

Hence the equilibrium condition in the market for high skilled labor is:

$$(19) \quad L_S(1+v_S)v_S \frac{h}{1-h} = \frac{(1-f_S)^2}{\kappa R} Y \left(\frac{\kappa R}{A}\right)^{1-\theta} \exp[(1-\theta)f_S].$$

Similar calculations lead to the labor market equilibrium in the market for low skilled labor:

$$(20) \quad L_N(1+v_N)v_N \frac{h}{1-h} = \frac{(1-f_N)^2}{\kappa R} Y \left(\frac{\kappa R}{A}\right)^{1-\theta} \exp[(1-\theta)f_N].$$

We divide equation (19) by equation (20) and get the following equilibrium condition:

$$(21) \quad \frac{L_S (1+v_S)v_S}{L_N (1+v_N)v_N} = \left( \frac{1-f_S}{1-f_N} \right)^2 \exp[(f_N - f_S)(\theta - 1)]$$

Note that this labor equilibrium condition describes a positive relationship between  $f_S$  and  $f_N$ , which is the positively sloped curve **L** in Figure 1 below. Its location is determined by the left hand side of (21), which depends only on the degree of labor regulation, namely on the firing costs parameter  $h$ .

### 3.5 General Equilibrium and the Effect of Labor Regulation

Figure 1 describes the two equilibrium conditions of the economy, equation (18) of the equilibrium in the goods markets, which is depicted by curve **G** and equation (21) of the equilibrium in the labor markets, which is depicted by curve **L**. The two curves intersect at a point **E**, which denotes the general equilibrium in the economy.

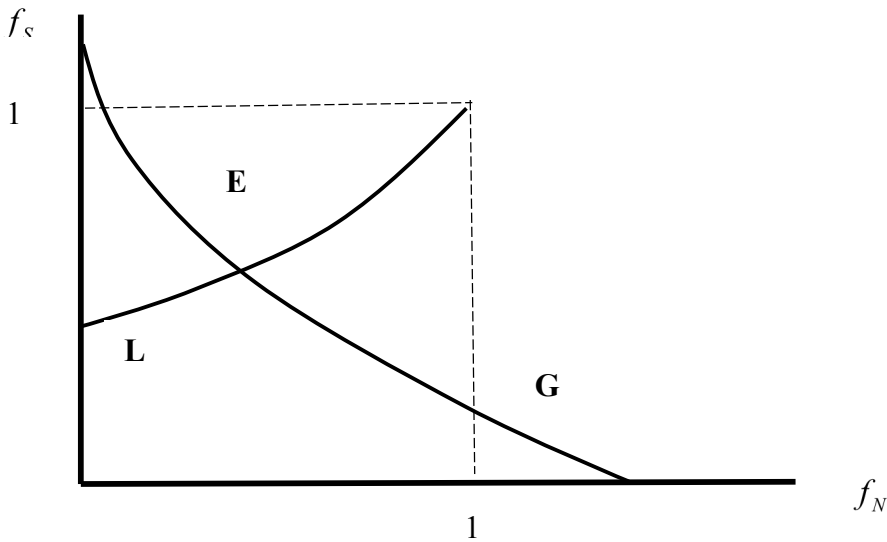


Figure 1: General Equilibrium with Endogenous Technologies

Proposition 1: The general equilibrium in this economy exists and is unique. It is always an interior solution:  $0 < f_S < 1$  and  $0 < f_N < 1$ . Furthermore, in equilibrium the high skill sector is more technologically advanced than the low skill sector:  $f_N < f_S$ . If labor regulation is increased, namely if  $h$  rises, the **L** curve shifts downward, and as a result  $f_S$  falls and  $f_N$  rises.

Proof in Appendix A.

Proposition 1 presents the main theoretical result of the model. Higher labor regulation reduces the level of technology in the high skill sector, but it increases the level of technology in the low skill sector. The intuition behind this result is the following. Increased firing costs lead firms to fire fewer workers and as a result both  $v_S$  and  $v_N$  decline. This reduces average productivity in both sectors and raises the average cost of labor. This should lead to more technology adoption in both sectors, but due to the constraints in the goods market, this happens only in the market where labor costs increase by more, and this happens in the market for low skill labor. Hence, this sector adopts more technologies, while the high skilled sector adopts less.

#### 4. Additional Results

In this section, we calculate the equilibrium levels of productivity of high and low skilled labor, the skill premium, namely the ratio between wages of high and of low skilled, and the capital ratio between the two sectors. These calculations are important for the empirical analysis, as we can measure these variables, but we do not directly observe  $f_S$  or  $f_N$ . In this section we also discuss some welfare implications of the model.

##### 4.1 Capital across Sectors

We derive the equilibrium amounts of capital in the two sectors, as they can be some measure to technology choice, if technology is embodied in capital. Capital in the high-skilled sector is:

$$K_S = \int_0^{f_S} \frac{s(i)\kappa}{1-i} di = \int_0^{f_S} \frac{P_S S}{R} di = f_S \frac{P_S S}{R} = f_S \frac{Y}{R} P_S^{1-\theta}.$$

Similarly, capital in the low-skilled sector is equal to:

$$K_N = f_N \frac{Y}{R} P_N^{1-\theta}.$$

We divide  $K_S$  by  $K_N$  and use equation (17) to obtain the following ratio of capital stocks:

$$(22) \quad \frac{K_S}{K_N} = \frac{f_S \exp[(1-\theta)f_S]}{f_N \exp[(1-\theta)f_N]}.$$

We next examine the effect of higher labor regulation, namely higher hiring costs  $h$ , on the capital ratio. This raises  $f_S$  and reduces  $f_N$ . A simple derivation shows that the numerator is a positive function of  $f_S$  if  $f_S(\theta-1) < 1$ . Since the technology frontier always satisfies  $f_S < 1$ , and since we assume that

$1 < \theta < 2$ , this condition holds. Hence, the numerator is a positive function of  $f_S$  and similarly, the denominator is a positive function of  $f_N$ . As a result, raising  $h$  reduces the capital ratio.

#### 4.2. Productivities of High and Low Skilled Labor

Since the aggregate intermediate goods,  $S$  and  $N$ , are produced by both labor and capital, we can describe their aggregate production functions. Appendix A shows that the production of  $S$  depends on  $E_S$ , labor in efficiency units, and on capital  $K_S$  in the following way:

$$(23) \quad S = A \exp[-f_S \ln f_S - 2(1-f_S) \ln(1-f_S) - f_S - f_S \ln \kappa] K_S^{f_S} E_S^{1-f_S}.$$

Equation (23) describes a Cobb-Douglas production function where the output-capital elasticity is equal to the technology frontier  $f_S$ .

We next write this production function by the numbers of workers in each sector, denoted  $M_S$  and  $M_N$ , respectively. The number of high skill workers is  $M_S = L_S \exp(b - v_S)$  while labor in efficiency units is  $E_S = L_S(1 + v_S) \exp(b - v_S)$ . Hence, effective labor is equal to:

$$E_S = (1 + v_S) M_S.$$

This means that  $1 + v_S$  is the average efficiency of high skilled workers. Substituting in (24) we get the following production function:

$$S = A_S K_S^{f_S} M_S^{1-f_S}.$$

Productivity of high skill production  $A_S$  is, therefore:

$$(24) \quad A_S = A \exp[-f_S \ln f_S - 2(1-f_S) \ln(1-f_S) - f_S - f_S \ln \kappa] (1 + v_S)^{1-f_S}.$$

In a similar way, the production of the low skill good is:

$$N = A_N K_N^{f_N} M_N^{1-f_N}.$$

Productivity of unskilled production is:

$$(25) \quad A_N = A \exp[-f_N \ln f_N - 2(1-f_N) \ln(1-f_N) - f_N - f_N \ln \kappa] (1 + v_N)^{1-f_N}.$$

Next, examine how labor regulation affects the productivities in the two sectors. There are two effects, one through changes in average efficiency of workers and one through changes in technology. A rise in  $h$  reduces  $v_S$  and  $v_N$ . Hence, average efficiency falls in both sectors and that reduces productivities  $A_S$  and  $A_N$ . The effect of the technology threshold  $f$  on productivity in each sector is more complicated. On the one hand, as technical change reduces the amount of goods produced by labor,

more workers operate in each intermediate sector, which increases productivity. On the other hand, as technology increases the number of mechanized sectors, less capital goes to each such sector, which reduces productivity. Appendix A examines these combined effects and finds that under plausible assumptions the effect of technology  $f$  on productivity, both in (24) and in (25), is positive. Hence, the effect of labor regulation on (24) through technical change  $f_S$  is negative, since labor regulation reduces  $f_S$ , while the effect of labor regulation on (25) through technology is positive.

Our model therefore predicts that the effect of labor regulation on  $A_S$  should be negative, both due to lower average efficiency of workers and due to the decline of technology in this sector. As for the effect of labor regulation on  $A_N$ , the result is ambiguous, as labor regulation reduces average efficiency of workers, but it raises technology in the low-skill sectors. Hence, this issue should wait to the empirical tests. If these tests reveal that regulation has a positive effect on  $A_N$ , it is an indication that the effect of technology is significant, as it overcomes the lower average efficiency of workers. An alternative test can examine the effect of labor regulation on the ratio between the two productivities, namely on  $\ln A_S - \ln A_N$ . We show in appendix A that the change in average labor efficiency increases this difference, while the change in technology reduces it. Hence the empirical test below can inform us on which effect is stronger, the labor efficiency or the technology adoption effect.

### 4.3 The Skill Premium

A measure of the skill premium in this model is the ratio between the high and low skill wage levels,  $W = w_S / w_N$ . Using equation (9) and the equivalent equation for low skill wage, we get:

$$W = \frac{w_S}{w_N} = \frac{p_S v_S}{p_N v_N}.$$

Applying equations (12) and (13), we get:

$$(26) \quad W = \frac{w_S}{w_N} = \frac{(1 - f_N) v_S}{(1 - f_S) v_N}.$$

The effect of a rise in  $h$  on the skill premium is ambiguous according to equation (26), as it increases  $v_S / v_N$  but reduces  $f_S$  and increases  $f_N$ , which both reduce  $W$ . The reason for this ambiguity is the following. Higher firing costs increase the sets of employed, both high and low skilled, but they increase the set of low skilled by more, hence they push the wage ratio up. Technology adoption works in the opposite direction. Firing costs increase  $f_N$  and hence low skilled workers work with more machines and their marginal productivity increases. The decline of  $f_S$  works in the same direction by reducing

wage of high skilled. We can therefore conclude, that firing costs reduce the skill premium only due to the mechanism of technology adoption. Hence, if the empirical tests reveal such a relationship, it should be interpreted as an additional support to the technology mechanism.

#### 4.4 Welfare

In this model labor regulation, which is in the shape of firing costs, reduces efficiency, as firing costs force firms to hire workers with relative low ability. But the policy has other effects on welfare as well. First, it reduces the set of unemployed. Second, it reduces the tax rate, since the number of unemployed is lower. Third and most, it reduces risk, as the group of people who receive low welfare payments is reduced. In this sub-section, we calculate the average expected utility at the beginning of life and examine how it behaves, as firing costs  $h$  increase. The average, or expected, utility of a skilled person at the beginning of life is:

$$U_S = \ln[w_S(1-t)] \int_{v_S}^{\infty} \exp(b-e) de + \ln[gw_S(1-t)] \int_b^{v_S} \exp(b-e) de.$$

Calculating this expected utility by using equations (9) and (12) we get:

$$U_S = \ln(1-t) + \ln v_S - \ln(1-f_S) - \ln(1-h) + \ln g - \ln g \exp(b-v_S) + \ln(R\kappa).$$

In a similar way we find that the expected utility of a low skill person is:

$$U_N = \ln(1-t) + \ln v_N - \ln(1-f_N) - \ln(1-h) + \ln g - \ln g \exp(a-v_N) + \ln(R\kappa).$$

The average expected utility in the economy is equal to:

$$\begin{aligned} \text{AVG}(U) &= L_S U_S + L_N U_N = \\ (27) \quad &= L_S \ln v_S + L_N \ln v_N - L_S \ln(1-f_S) - L_N \ln(1-f_N) - \frac{h}{1-h} \ln g [L_S v_S + L_N v_N] + \\ &\quad + \ln(1-t) - \ln(1-h) + \ln(R\kappa) + \ln g. \end{aligned}$$

Calculation of the average expected utility across the population requires also finding the equilibrium tax rate. Direct calculation of the tax rate, paid by all workers to finance the income of the unemployed minus the firing costs, leads to the following:

$$t = (g-h) \frac{L_S \frac{v_S}{1-f_S} [1-h-v_S h] + L_N \frac{v_N}{1-f_N} [1-h-v_N h]}{L_S \frac{v_S}{1-f_S} [(1-g)v_S h + (1-h)g] + L_N \frac{v_N}{1-f_N} [(1-g)v_N h + (1-h)g]}.$$

We can now calculate the average expected utility using the equilibrium tax rate  $t$ . Since this calculation is quite complicated analytically, we present a numerical example. For this calculation, we

choose the following parameters:  $a = 1$ ,  $b = 2$ ,  $L_S = 0.25$ ,  $(A/\kappa R)^{1-\theta} = 1.5$ , and  $g = 0.5$ . The value of aggregate welfare,  $AVG(U)$ , is presented in Figure 2. This figure shows that despite its adverse effect on efficiency, labor regulation increases welfare, since it is risk reducing, it increases employment, reduces unemployment payments and thus reduces taxes.

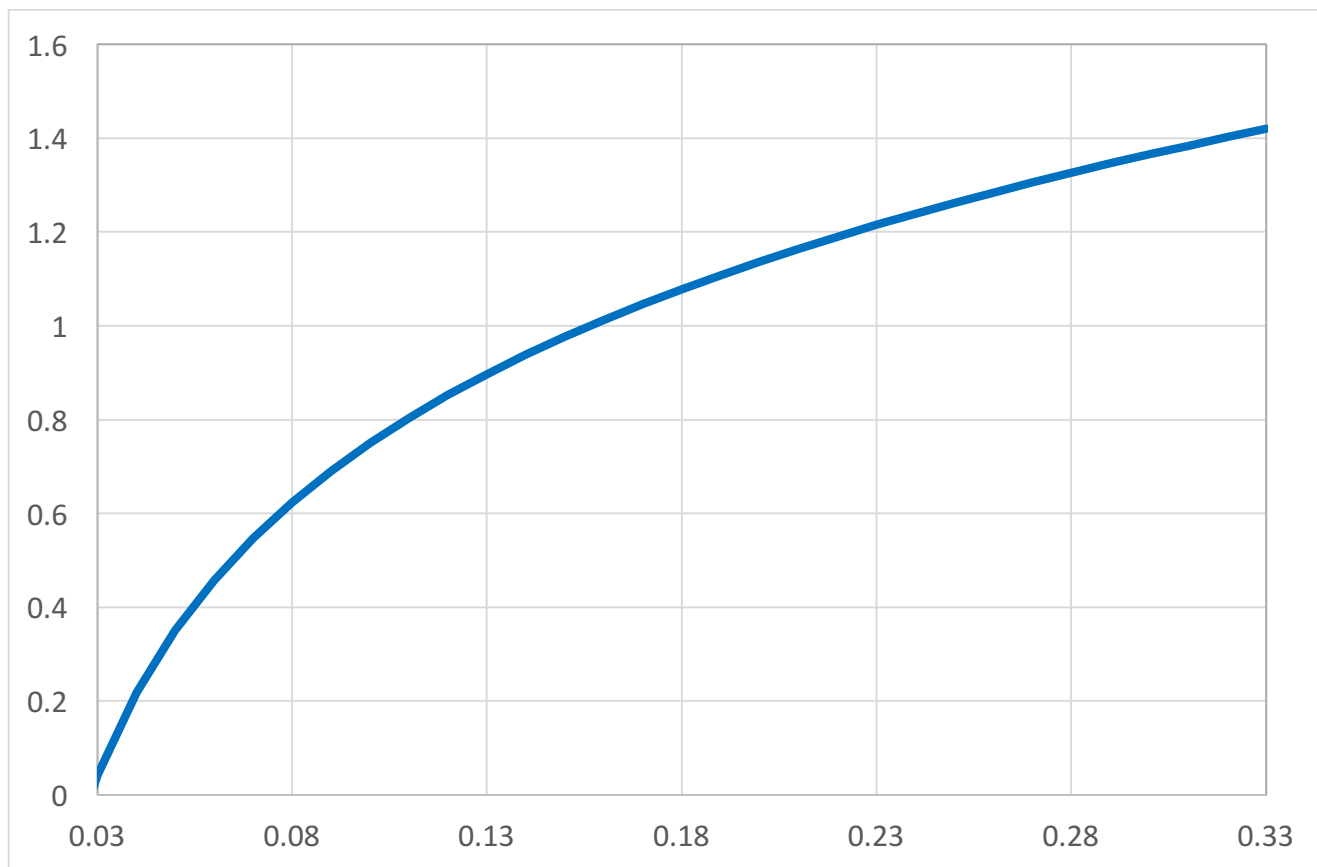


Figure 2: Welfare as a Function of the Rate of Firing Costs  $h$

#### 4.5 An Economy without Technological Choice

In this Sub-Section we describe briefly a counter model which is useful for comparison with our results. It is very similar to our model, but it does not have labor cost reducing technical change. Consider a model with firing costs, which is similar to the one described in Section 2, except that production of the high skill good and the low skill good are described by standard production functions. The production function in this economy is described by:

$$(28) \quad Y = \left[ \left( AK_S^\alpha E_S^{1-\alpha} \right)^{\frac{\theta-1}{\theta}} + \left( AK_N^\alpha E_N^{1-\alpha} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}.$$

Here,  $\alpha$  is the output elasticity of capital both in the high and in the low skill sectors.

Since this is a relatively standard model we do not present here the full solution of the model and just present some of the main results on empirical implications.<sup>15</sup> The first is the capital ratio between the skilled and unskilled sector:

$$\frac{K_S}{K_N} = \left( \frac{E_S}{E_N} \right)^{\frac{1-\alpha}{\theta-1}} = \left[ \frac{L_S (1+v_S)v_S}{L_N (1+v_N)v_N} \right]^{\frac{1-\alpha}{\theta-1}}.$$

Since a rise in labor regulation reduces  $v_S$  by less than  $v_N$  it increases the capital ratio as well. This empirical implication is opposite to the one in our model with technology choice. Calculation of the productivities with respect to the number of worker yields:

$$A_S = A(1+v_S)^{1-\alpha} \text{ and } A_N = A(1+v_N)^{1-\alpha}.$$

Hence, higher labor regulation reduces both productivities, since only the average efficiency effect is operating in this model. In our main model the effect of technology adoption is added to this effect and might even change the overall effect of labor regulation on  $A_N$  from negative to positive.

## 5. Data

We use three different variables to measure labor regulation. The first is an index of employment protection legislation, denoted EPL. The second is union density, which measures the share of unionized workers and is denoted UD. The third is union coverage, which measures the share of workers covered by collective bargaining and is denoted UC.<sup>16</sup> EPL is directly related to the firing cost variable  $h$  in the theoretical model, but the union variables also measure labor regulation, since labor unions in one way or another raise the wages of the lower paid workers and raise firing costs.

Since the main claim of this paper is that changes in labor regulation affect the choice of technology in high and low skill sectors, the ideal empirical strategy would be to test the effect of regulation on some measure of technology adoption. Unfortunately these data are not comprehensively

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<sup>15</sup> Full proofs of these results are available upon request.

<sup>16</sup> We also experimented with other variables. One is the ratio of minimum wage to average wage, but we decided not to include it in the analysis, since it is clearly an endogenous variable. Another variable we examined is unemployment benefits. We report on its effects in Section 10.

available. Comin and Hobijn (2004, 2009, 2010) and Comin and Ferrer (2013) have started to collect these data, but what is available is still insufficient for estimating our model, since the number of technologies in this data set which can be easily classified between high and low skill sectors is not sufficiently large. Hence, we represent technology adoption with three variables. The first is the ratio between capital in high skilled sectors and capital in low skilled sectors, which we denote KRATIO. According to our model, it should fall with labor regulation, while in the alternative model it should rise. The second variable is productivity; we denote the high skill productivity by AS and the low skill productivity by AN. According to our model, labor regulation should reduce AS and increase AN, if the technology effect dominates the average efficiency effect. In the counter model it should reduce both. In addition to these variables, we also examine a third variable, which is not in the model but should be correlated with technology adoption. This variable is country patent production per capita in high and in low skilled sectors, denoted PAT\_HS and PAT\_LS respectively. Table B.1 in Appendix B lists the data sources for all variables.

We next describe the variables in more detail. EPL, employment protection legislation, from OECD (2013), measures procedures and costs involved in laying-off individuals or groups of workers. More specifically, it is a survey among experts, asked 21 questions in three areas: protection of workers against individual layoff, regulation of temporary employment, and specific requirements for collective layoffs. The survey processes the answers on a scale between 0 and 6, where higher values represent stricter regulation, and then calculates a general score. The variable UD, from Visser (2013), measures the share of union members among workers. It should be correlated with labor regulation for three reasons. First, if labor unions are stronger, they apply more pressure on the government to regulate the labor market and to choose policies that reduce wage inequality.<sup>17</sup> Second, the government can also affect union strength by its labor market policies, both as an employer and as a labor market regulator. Third, governments that tend to regulate labor markets more heavily are usually more favorable to workers and thus tend to curb union activity less. Union coverage, UC, measures the share of workers whose wages are covered by collective bargaining. This measure is of course higher than union density and in some cases, like in France, it is much higher. The correlation between union density and union coverage is 0.54. Table 1 presents the descriptive statistics of all the variables used in the model.

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<sup>17</sup> For a discussion of how unions promote policies that reduce wage inequality, especially in Europe, see Blau and Khan (2002) Alesina and Glaeser (2004) and Kramarz (2007).

[Insert Table 1 here]

The measures of labor regulations and unionization vary significantly across countries. In 2000, union density was less than 20 percent in France, (although union coverage was much higher) USA, Spain, and Korea, while it was around 80 percent in Sweden, Finland, and Denmark. While union coverage was on average 80 percent over the period in some countries and much higher than UD, it was much lower in the USA and very similar to union density. In the USA it was 22 percent on average, and with a declining trend, so that it reached 13 percent in 2011. In 2000 the score for employment protection legislation, EPL, was close to 0 for the USA and lower than 1.5 for Canada, UK, New Zealand, Ireland and Australia. At the same year it was around 3 for Greece and the Netherlands and it was close to 5 in Portugal. Labor regulation not only differs across countries, but also varies over time. For example we have observed a significant deregulation of labor markets since the 1980s, which was large in the US and milder in Europe.

The variable KRATIO is calculated from the amounts of capital in low skill and high skill sectors, which are derived from two sources. First, we get the quantities of capital per sector from the EU KLEM database, see O'Mahony and Timmer (2009) which contains information on sectors classified according to the international classification ISIC revision 3. The data contain capital amounts for 56 two digit industries, and ends in 2005. We classify these sectors to high-skilled and low-skilled following Robinson, Stokes, Stuijvenwold and Van Ark (2003) who classify sectors in 4 categories of skill, low-skilled, low-intermediate-skilled, high-intermediate-skilled and high-skilled. Using data on the distribution of skill in sectors, they create three separate taxonomies of sectors by skill, one based on data from the US and the UK, one based on Eurostat data of all EU countries and one on Eurostat data in the 7 largest EU countries. As the three taxonomies are quite similar, they form a final taxonomy that summarizes all three.<sup>18</sup> We use this classification, but group together the high and high-intermediate skill sectors into high skilled and the low and low intermediate skilled into low skilled. For each country, we aggregate the amounts of capital for the high skilled sectors and for the low skilled sectors and then calculate their ratio, which is denoted KRATIO.

In the calculation of productivities of high and low skilled sectors, we follow Caselli and Coleman (2006) and use similar formulas to calculate productivities from the available data. Since we

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<sup>18</sup> Table II.9a in the chapter.

do not observe the model's technology frontiers  $f_S$  and  $f_N$ , we use the share of capital in output instead and denote it by  $f$ , as an average between the two frontiers. The measured productivity of the high skill sector is:

$$(29) \quad AS = \left( \frac{w_S M_S}{w_S M_S + w_N M_N} \right)^{\frac{\theta}{\theta-1}} \frac{Y}{K_S^f M_S^{1-f}}.$$

The productivity of the low skill sector is:

$$(30) \quad AN = \left( \frac{w_N M_N}{w_S M_S + w_N M_N} \right)^{\frac{\theta}{\theta-1}} \frac{Y}{K_N^f M_N^{1-f}}.$$

Appendix A shows how these formulas fit our model as well. It also shows that these measures are biased with respect to the model productivities, but the biases are in direction of our theoretical prediction. A rise in the labor regulation variable  $h$  reduces  $A_S$  relative to AS. Thus, if our empirical tests show that labor regulation reduces the measured variable (29), the true effect on high skill productivity is even stronger. Similarly, a rise in  $h$  increases  $A_N$  relative to (30). Again, if our tests show that labor regulation tends to increase (30), the true effect on productivity is even stronger.

We calculate the two productivities empirically by using data from EU KLEMS, and from PWT 8.0, described in Feenstra, Inklaar and Timmer (2015). The data on labor, capital, and output are from the EU KLEMS data set. The values of high and low skill wage bills are also from EU KLEMS. We deviate from Caselli and Coleman (2006) in defining high skilled as workers with secondary education and above.<sup>19</sup> The elasticity of substitution between high and low skill,  $\theta$ , is assumed to be 1.4, as in Caselli and Coleman (2006), and the  $f$  is taken from data on labor shares in PWT 8.0. Note, that the productivities AS and AN are calculated by using the separate amounts of capital for high and low skill sectors. Such data are available only for countries covered by EU KLEMS. For some empirical tests we extend the calculation of productivities to more countries by using data on the aggregate amount of capital instead of sector specific capital. This is clearly a less accurate measure, but we use it in Appendix B, for robustness.

The information on patent creation is derived from the World Intellectual Property Organization, WIPO (2014). Our data consist of the numbers of high skill patents and low skill patents in a set of

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<sup>19</sup> Since our sample of countries includes only OECD economies, this classification is more appropriate than Caselli and Coleman (2006), who use a larger sample of countries and define high skill as primary education. We also tried some form of tertiary education as a definition of high skill, but the results don't change much.

countries over many years. The taxonomy of patents by high and low skilled follows Schmoch (2008). We have calculated for each country and each year the numbers of high skill patents and low skill patents per 1000 people.

## 6. Descriptive Evidence

Europe has strong labor regulation, while the US has had traditionally much less and also went through significant deregulation of labor markets since the 1980s. Table 2 compares the US and Europe with respect to our indicators of technology adoption, namely the capital ratio, productivities and patent creation.<sup>20</sup> Table 2 shows that the capital ratio between high and low skill sectors is higher in the US than in Europe and it also grows faster. It also shows that high skill productivity is higher in the US than in Europe, while low skill productivity is higher in Europe than in the US. Table 2 also examines the ratio of high to low skill patents and shows that this ratio is higher in the US than in Europe. These descriptive statistics are consistent with the empirical implications of our model.

[Insert Table 2 here]

Figure 2 describes the capital ratios for the US and for Europe over the years. It shows the same pattern as emerges from Table 2, but the picture is more detailed. The capital ratio in the US is higher than in Europe and the gap between the two regions is increasing over time, as labor markets in the US become increasingly less regulated.

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<sup>20</sup> EU15 are the Western European countries before EU enlargement of 2005. EU27 are all European countries in the EU after the entry of 10 Eastern European countries in 2005 and Bulgaria and Romania in 2007. We have data for all these countries for patents and productivity levels. Finally, the European countries for what we have data in EU KLEMS are Austria, Germany (West before 1990), Denmark, Finland, UK, Italy, Netherland and from 1995 we have data for Sweden, Portugal, Slovenia and Czech Republic.

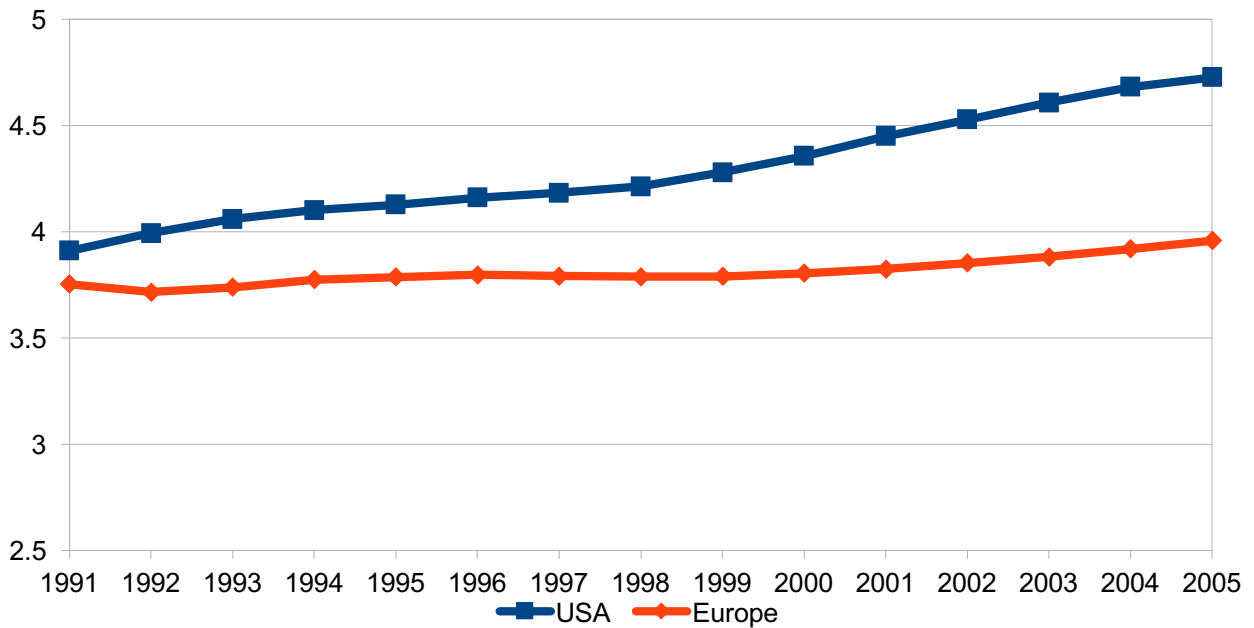


Figure 2: KRATIO in Europe and in the US in 1991-2005

Figure 3 describes the ratio of AS to AN in a few selected countries, US, UK, Germany, Italy and Austria. As figure 3 shows, this ratio is significantly higher for the US and the UK than in the other countries, where labor markets are more regulated. Furthermore, the ratio in the US and the UK is not only higher, but it rises much more than in the other countries. Thus, Figure 3 indicates that productivity of high skill sectors rises with labor deregulation by more than productivity of low skill sectors. This lends support to the predictions of our model with respect to productivities, which we study in more detail below.

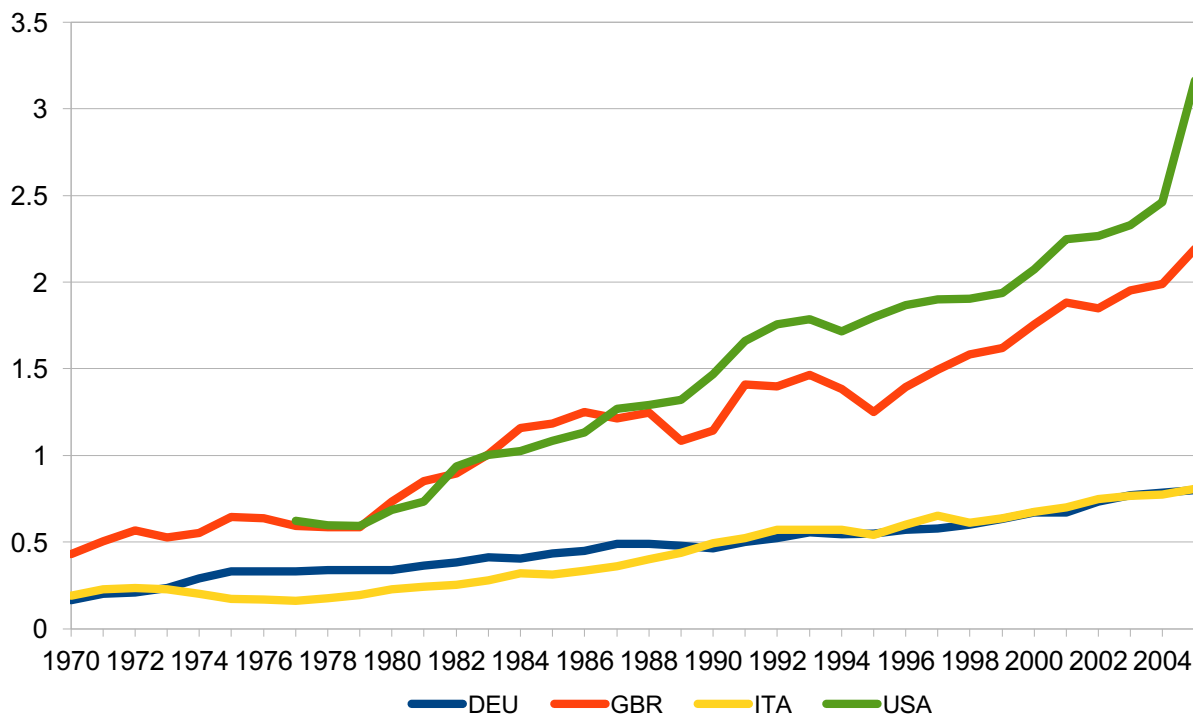


Figure 3: The Ratio of AS to AN across Selected Countries in 1970-2005

Table 3 presents a more systematic comparison between countries with more and less labor regulation. We divide the countries to low and high EPL, namely above and below the mean, and compare our indicators of technology adoption for these groups of countries. Countries with higher regulation, whether higher EPL, higher UD or higher UC, have a lower capital ratio, higher low skill productivity, lower high skill productivity, and a lower ratio of PAT-HS to PAT-LS.

[Insert Table 3 here]

### 7. Labor Regulation and the Capital Ratio

Our model implies that more labor regulation would reduce the capital ratio. The results of our tests are in Table 4. Our dependent variable, KRATIO, is strongly persistent over time, even if there is no evidence of a unit root. A Wald test for all the specifications of Table 4 rejects the null hypothesis of no first-order autocorrelation. Thus, we correct the standard errors according to the procedure of Driscoll and Kraay (1998) and these are the errors reported in Table 4. We obtain almost identical results by

clustering the standard errors for countries.<sup>21</sup> Note also that according to Figure 2 most variability in KRATIO is across countries, but there is some variability over time, though smaller. We therefore test the effects of labor regulation on KRATIO in panels, to use both variability across countries and over time.

[Insert Table 4 here]

The explanatory variables in Table 4 are our three measures of labor regulation, a constant and two additional variables. One variable is a dummy for the years after 1991, to control for the unification of Germany, since capital ratios differed in Germany before and after the unification.<sup>22</sup> The second additional variable, Secondary Education, is the percentage share in the population of people with secondary education. We add this variable to account for an alternative explanation for changes in the capital ratio. Both variables happen to have a small and insignificant effect on the results. In addition to testing the direct effects of the measures for labor regulation, we also test for potential interaction between the two main variables, where we test the effect of EPL separately for countries with high and with low union densities. We also include year dummies.

Overall the regressions in Table 4 support our model and show that labor regulation is negatively correlated with the capital ratio between the high and low skill sectors. The regressions show that the employment protection legislation EPL has a negative effect, of similar size, in all six regressions, and it is significant at least at the 5% level (or better) in all the specifications. UC is significant at the 10 per cent level in column 3. UD seems to be dominated by UC which is indeed the most relevant variable in practice. In column (4) we add to the regression the supply of skilled versus unskilled workers. The variable has a positive coefficient suggesting that a higher supply of skilled workers is correlated positively with the capital ratio. Finally, in the last two columns, we check if employment protection legislation has an asymmetric effect relative to the presence of unions in the economy. One can possibly claim that in highly unionized countries regulation is less effective, as unions already work in favor of labor. Actually columns (5) and (6) show that this claim is not supported by the data, as the effect of

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<sup>21</sup> These results are available upon request.

<sup>22</sup> We include the dummy for 1991 only for groups of countries, which includes Germany.

EPL on the capital ratio is stronger in countries with high union density than in countries with low union density.<sup>23</sup>

In Table B.2 in appendix B we present two additional specifications. We first examine the effect of labor regulation on the change in the capital ratio, denoted  $\Delta\text{KRATIO}$ , in a standard panel regression with country fixed effects, in regressions (1)-(3) in that table. We then return to the regressions on  $\text{KRATIO}$ , but this time with the variable lagged by one year. These regressions in columns (4)-(6) are dynamic panels estimated with System GMM to avoid the Nickell bias. The results in Table B.2 also show a negative effect of labor regulation on the capital ratio and thus strengthen the message of Table 4. A related issue to the serial correlation of the  $\text{KRATIO}$  is that it could reflect a time trend. We have accounted to that as well by adding a time trend, linear and non-linear, to the regressions on  $\text{KRATIO}$ . The coefficient of EPL on  $\text{KRATIO}$  is still negative and significant at 1 percent, although it becomes smaller.<sup>24</sup> Hence, the main lessons of this Section do not change with the addition of a trend.

## 8. Labor Regulation and Productivities

In this section we examine the relationship between labor regulation and the productivities of high and low skill sectors, AS and AN respectively, as calculated in Section 5. According to Section 4, labor regulation reduces average efficiency of workers in both sectors, as it adds low efficiency workers. This applies both to our model and to the standard counter model, but in our model productivity is also affected by technology choice and that reduces AS and increases AN. Hence, examining the correlation between labor regulation and the two productivities allows us to assess the empirical validity of the two models. Table 5 presents the tests with the productivities of the countries from the EU KLEMS data set, as their calculation follows equations (29) and (30) most accurately.

[Insert Table 5 here]

The bottom line of this table is that without year dummies the pattern of the coefficients is broadly consistent with the implication of our model, but with year dummies the results are inconclusive at best. Without year dummies the effect of employment protection legislation EPL on AS is negative

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<sup>23</sup> We also find that the effects of labor regulation on productivities and on patents, which are discussed in the following sections, do not change sign in highly unionized countries.

<sup>24</sup> These results are available upon request.

but insignificant, but after adding the variables UD, the effect of EPL becomes negative and highly significant. The effect of UD on AS is negative and highly significant as well, while union coverage UC has an insignificant effect. The effects of labor regulation on AN are positive, larger in size and more significant. Both EPL and UD increase  $\ln(\text{AN})$  significantly in all specifications and even UC has a positive and significant effect on  $\ln(\text{AN})$ .

In Table 5a we look at the difference between AS and AN. Our model would imply a reduction of this difference for higher labor regulation. The results of this Table are broadly consistent with these implications of the model even with year dummies and especially for EPL.

We next discuss some potential alternative mechanisms. In a series of papers, Acemoglu and Pischke (1999a, 1999b) have claimed that unemployment insurance or similar transfers enable workers to acquire human capital and that is true mainly for low skill workers. This can, therefore, be an alternative explanation to the rise in AN, that we observe. But such a mechanism should lead to a positive effect of labor regulation also on AS, while our empirical analysis shows that this effect is negative. One other point, raised by Moene and Wallerstein (1997), is that labor regulation might increase productivity by forcing less productive firms to quit. Another possibility is that since countries with high labor regulation tend also to have more vocational education, like apprenticeships, this also raises productivity in low skill sectors. While all these mechanisms are plausible, they cannot explain the negative correlation between labor regulation and productivity in the high skill sector.

Finally, while Table 5 and 5a present results from a small sample of countries, we extend these results in Table B.3 in Appendix B. There we calculate the productivities for a wider set of countries in OECD, for which we use of information on aggregate capital instead of sector capital. As noted above, this is a less accurate calculation of productivity. The results of Table B.3 and B4 are similar qualitatively to those of Table 5 and 5a.

## 9. Labor Regulation and R&D

We examine in this section whether labor regulation is positively correlated with creation of low skill technologies and negatively with creation of high skill technologies. Our measures of innovation are the number of patents per 1000 people in the high and the low skill sectors, PAT\_HS and PAT\_LS respectively, as defined in Section 5.

Table 6 presents the regressions of patent creation on labor regulation, where we use moving averages of patents over intervals of five years. The reason is that patent data reflect the end of rather

long R&D activities, and the ending time of such activity is itself random, which adds noise to the data. Hence, patent data might be more erratic than the underlying data on R&D activity, which are the true data we should use in our analysis, if it were observable.<sup>25</sup> In all the regressions in Table 6 we also add a variable that represents the overall patent activity of the country, as we know that countries differ significantly in their ability to conduct R&D. The variable we use to control for this ability is the number of total patents in the country per 1000 people with a lag. We use a lag to avoid high correlation between this variable and the dependent variables. We denote this variable by PAT\_L1.

[Insert Table 6 here]

Columns (1)-(3) in Table 6 show that labor regulation has a negative effect on high skill patents in the economy. The results are statistically significant for EPL when it is alone and where UD is added to the regression. EPL becomes insignificant in column (3) with the introduction of UC. In this regression UD becomes negative and highly significant. Hence, in all three regressions the effect of labor regulation is negative and it is significant for at least one of the variables that account for labor regulation. Columns (4)-(6) present the results of the regressions for low skill patents. They show that labor regulation is positively correlated with creation of low skill technologies in a country, as its effect on PAT\_LS is positive, especially in regression (6), which includes all the explanatory variables. Again, these results support the main claim in the paper, that labor regulation is correlated positively with low skill technology and negatively with high skill technology.

In the last columns of each part of this table (4 and 8) we report results with year dummies. Here our result supportive of the model disappear. It is not clear why and it is not clear why time dummies should matter for the ratio of patent in different sectors. This is a puzzling result worth of further research.

Finally, we also examined the effect of unemployment benefits on our three measures of technology adoption, as it also represents labor regulation. The variable we used is GRR, gross replacement ratio, in the first and the second year. The results are mixed. GRR reduced the capital ratio, like the other variables that we use to measure labor regulation, but it reduced low skill productivity, unlike the other measures of labor regulation. The effect of GRR on patents was insignificant. One

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<sup>25</sup> It is important to note that this is not the case with respect to the variables in the previous sections, KRATIO and productivities, and this is the reason why we use such averaging only in this section.

possible explanation for such results is that there is a trade-off between EPL and unemployment benefits, as documented by Boeri, Conde-Ruiz, and Galasso (2004) and Neugart (2007). Hence, the effect of unemployment benefits on technologies should not be similar to the effects of other labor regulations. These results are available upon request.

## 10. Labor Regulation and Wage Dispersion

Our model implies that a rise in labor regulation increases the cost of low skill labor by more than the cost of high skill labor. This mechanism implies that we should also observe a negative correlation between labor regulation and the dispersion of wages. This section examines this implication. This negative correlation between labor regulation and the dispersion of wages should appear also in the standard counter model in Section 4, but our model implies that the effect of labor regulation on wage dispersion is larger due to amplification by technical change.

We test this effect by regressing a measure of wage inequality on our variables of labor regulation. We use the observations of the Gini index from the inequality database of UNU-WIDER (2015), which computes them on job earnings. Table 7 presents the results of these regressions, which include year dummies do not include country fixed effects for the EPL. The reason is that due to a small number of observations EPL is single valued for almost all countries over time, so it becomes collinear with the fixed effect. As a result, the first four columns are pooled regressions, while the fifth column checks for the country fixed effects in a regression of Gini over UD. Overall the regressions present reasonable evidence of a negative effect of EPL, UD and UC on the Gini index of job earnings.

[Insert Table 7 here]

## 11. Conclusions

A vast literature studies why countries adopt different technologies. While most of this literature focuses on differences between developed and less developed countries, this paper focuses instead on differences in technology between developed economies. The paper claims that such differences may arise between high and low skill sectors, and that they could be a result of differences in labor market policies. Our model shows that labor market regulation changes the wage premium between high and low skilled and that affects the incentive to adopt technologies. This happens when technologies are embedded in machines that replace workers for specific jobs, or more generally in a model of ‘labor cost induced

technical change.’ As a result, countries with high labor regulation adopt more technologies in the low-skill sectors and less in the high-skill sectors, while countries with low labor regulation adopt more technologies in the high-skill sector.

We examine various empirical implications of the model. We identify some measures of labor regulation and then we test how they affect technology adoption. The ratio of capital in the high and low skill sectors falls with labor regulation in our model, while it should rise in a standard model without technical change. Next, we measure the productivities of high and low skill workers in each country and examine how they react to labor regulation. Our model predicts that labor regulation should lower productivity in the high skill sector and raise productivity in the low skill sector, while according to the standard model it should lower productivity in both sectors. We find mixed results. We then look at technology creation, which should be correlated with technology use. The results on patent are ambiguous and depend on the specification used. Overall, the data support reasonably well some (but not all) of the predictions of the model. Further empirical research may show additional light on issues left open.

## Tables

Table 1: Descriptive Statistics

Variable	No. of Observations	Mean	Standard Deviation	Minimum	Maximum
EPL	846	2.20	0.84	0.26	5.0
UD	1342	0.39	0.23	0.06	0.99
UC	1312	0.61	0.28	0.01	1.00
KRATIO	464	3.40	1.08	1.37	5.70
Ln(AS)	419	1.29	1.07	-0.31	4.29
Ln(AN)	419	1.75	1.14	0.4	4.73
PAT_HS	1116	0.34	0.42	0.00	2.47
PAT_LS	1116	0.20	0.22	0.00	1.34

Table 2: Capital Ratio, Productivity and Patents for USA and European Countries

Variable	KRATIO in 1994-2005	Annual Change of KRATIO (%)	Average Ln(AS)	Average Ln(AN)	Share of PAT-HS in Total Patents
USA	4.39	0.57	1.288	0.952	0.73
EUROPE 15	3.51*	0.15*	0.893*	1.354*	0.51

\* Computed for eleven countries in EU15 for which EU KLEMS data are available.

Table 3: Indicators for Technology Adoption vs. High and Low Labor Regulation

Measures of Labor Regulation	EPL above mean	EPL below mean	UD above mean	UD below mean	UC above mean	UC below mean
Annual Change of KRATIO (%)	0.15	0.16	0.09	0.16	0.16	0.19
Average Ln(AS)	6.22	6.73	6.02	6.50	5.90	7.02
Average Ln(AN)	6.45	6.45	6.83	6.42	6.27	6.91
Share of PAT-HS in Total Patents	0.52	0.62	0.598	0.602	0.56	0.63

Table 4: Labor Regulation and the Ratio of Capital

Explanatory Variables	Dependent Variable: KRATIO					
	Full sample				UD>mean	UD<mean
	(1)	(2)	(3)	(4)	(5)	(6)
EPL	-0.392 <sup>***</sup> (0.085)	-0.433 <sup>***</sup> (0.101)	-0.657 <sup>**</sup> (0.184)	-0.535 <sup>**</sup> (0.219)	-1.521 <sup>***</sup> (0.392)	-0.187 <sup>**</sup> (0.084)
UD		-0.379 (0.350)	0.324 (0.695)	1.072 (0.997)		
UC			-0.855 <sup>*</sup> (0.424)	-0.953 <sup>**</sup> (0.423)		
Secondary Education				0.392 <sup>***</sup> (0.123)		
DUMMY 1991	-0.161 (0.141)	-0.161 (0.140)	-0.165 (0.137)	-0.175 (0.138)	omitted	-0.277 <sup>*</sup> (0.140)
R <sup>2</sup> (within)	0.24	0.24	0.23	0.25	0.48	0.35
Observations	281	281	264	264	91	190
No. of Countries	15	15	15	15	8	12

1. All regressions contain countries fixed effects and year dummies.  
2. Significance notations are \*\*\* for 1%, \*\* for 5% and \* for 10%.  
Driscoll-Kraay (1998) standard errors.

Table 5: Labor Regulation and Productivities of High and Low Skill Sectors

Explanatory Variables	Dependent Variable: ln(AS)				Dependent Variable: ln(AN)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EPL	-0.093 (0.074)	-0.180 <sup>***</sup> (0.062)	-0.290 <sup>***</sup> (0.096)	0.098 (0.098)	0.515 <sup>***</sup> (0.075)	0.609 <sup>***</sup> (0.061)	0.626 <sup>***</sup> (0.098)	0.145 (0.095)
UD		-1.760 <sup>***</sup> (0.164)	-1.891 <sup>***</sup> (0.266)	-0.144 (0.320)		1.883 <sup>***</sup> (0.164)	1.294 <sup>***</sup> (0.271)	-0.677 <sup>**</sup> (0.311)
UC			0.105 (0.240)	0.100 (0.219)			0.612 <sup>**</sup> (0.244)	0.533 <sup>**</sup> (0.213)
R <sup>2</sup> (within)	0.01	0.32	0.34	0.54	0.16	0.45	0.37	0.60
Year dummies	N	N	N	Y	N	N	N	Y
Observations	261	261	244	244	261	261	244	244
Countries	14	14	14	14	14	14	14	14

1. All regressions include country fixed effects.  
2. Significance notations are \*\*\* for 1%, \*\* for 5% and \* for 10%.

Table 5a: Labor Regulation and Difference of Productivities

Dependent variable: Difference between Skilled and Unskilled productivity						
Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)
EPL	-0.608*** (0.118)	-0.790*** (0.081)	-0.917*** (0.131)	-0.167*** (0.054)	-0.196*** (0.163)	-0.047 (0.090)
UD		-3.644*** (0.217)	-3.185*** (0.364)		-0.218 (0.239)	0.533* (0.296)
UC			-0.507 (0.328)			-0.433** (0.202)
R <sup>2</sup> (within)	0.10	0.58	0.54	0.84	0.84	0.85
Year dummies	N	N	N	Y	Y	Y
Obs	261	261	244	261	261	244
Countries	14	14	14	14	14	14
1. All regressions contain countries fixed effects						
2. Significance notations are *** for 1%, ** for 5% and * for 10%.						

Table 6: Labor Regulation and High and Low Skill Patents

Explanatory Variables	Dependent Variable: PAT_HS				Dependent Variable: PAT_LS			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PAT_L1	0.697*** (0.01)	0.708*** (0.01)	0.654*** (0.009)	0.657*** (0.009)	0.271*** (0.003)	0.274*** (0.004)	0.271*** (0.005)	0.272*** (0.005)
EPL	-0.029*** (0.01)	-0.035*** (0.01)	0.003 (0.015)	0.024 (0.015)	0.008 (0.006)	0.009 (0.007)	0.025*** (0.008)	-0.003 (0.008)
UD		-0.039 (0.034)	-0.175*** (0.059)	0.037 (0.074)		0.098*** (0.019)	0.188*** (0.033)	-0.019 (0.040)
UC			0.017 (0.053)	0.015 (0.051)			-0.004 (0.030)	-0.009 (0.028)
R <sup>2</sup> (within)	0.94	0.94	0.91	0.92	0.88	0.88	0.84	0.87
Year dummies	N	N	N	Y	N	N	N	Y
Obs.	835	701	601	601	835	701	601	601
Countries	42	36	33	33	42	36	33	33
1. All regressions include country fixed effects.								
2. Significance notations are *** for 1%, ** for 5% and * for 10%.								

Table 7: Labor Regulation and Wage Dispersion

Explanatory Variables	Dependent Variable: Gini of Wages				
	(1)	(2)	(3)	(4)	(5)
EPL	-0.055*** (0.017)		-0.045** (0.018)		
UD		-0.245*** (0.058)	-0.096 (0.129)		-0.005 (0.045)
UC				-0.214*** (0.029)	
R <sup>2</sup>	0.42	0.46	0.46	0.87	
R <sup>2</sup> (within)					0.75
Observations	49	106	46	64	106
Estimation	OLS	OLS	OLS	OLS	FE
1. All standard errors are robust. All regression contain year dummies. Last column contains country fixed effects. 2. Significance notations are *** for 1%, ** for 5% and * for 10%. 3. Source: UNU-WIDER.					

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## Appendix A: Proofs

### Derivation of Equation (10)

The zero profit condition is:

$$p_S(i) \int_{v_S(i)}^{\infty} e \exp(b-e) de - w_S \int_{v_S(i)}^{\infty} \exp(b-e) de - hw_S \int_s^{v_S(i)} \exp(b-e) de = 0.$$

Calculating the integrals in this condition yields:

$$\begin{aligned} & p_S(i)[v_S(i) \exp[b - v_S(i)] + \exp[b - v_S(i)]] - w_S \exp[b - v_S(i)] - hw_S [1 - \exp[b - v_S(i)]] = \\ & = p_S(i)[v_S(i) \exp[b - v_S(i)] + \exp[b - v_S(i)]] - (1-h)w_S \exp[b - v_S(i)] - hw_S = 0. \end{aligned}$$

Use equation (9) to substitute for  $p_S(i)$  and get:

$$\frac{w_S(1-h)}{v_S(i)} \exp[b - v_S(i)][v_S(i) + 1] - (1-h)w_S \exp[b - v_S(i)] = hw_S.$$

Eliminating  $w_S$  on both sides leads to equation (10).

### Derivation of Equation (16)

Equating the supply price (14) with the demand price (15) and substituting the quantities  $s(i)$  in the production function of the high skill good (3), we get:

$$\begin{aligned} \ln S &= \ln A + \int_0^1 \ln \frac{P_S S}{P_S(i)} di = \ln A + \ln S + \ln P_S - \int_0^{f_S} \ln \frac{\kappa R}{1-i} di - \int_{f_S}^1 \ln \frac{\kappa R}{1-f_S} di = \\ &= \ln A + \ln S + \ln P_S - \ln(\kappa R) + (1-f_S) \ln(1-f_S) + \int_0^{f_S} \ln(1-i) di. \end{aligned}$$

Calculating the integral yields  $\int_0^{f_S} \ln(1-i) di = -(1-f_S) \ln(1-f_S) - f_S$  and hence:

$$\ln P_S = f_S + \ln(\kappa R) - \ln A.$$

We show similarly that:  $\ln P_N = f_N + \ln(\kappa R) - \ln A$ . This proves equation (16).

### Derivation of Equation (18):

From the first order conditions of production of the final good (17), we get  $S = YP_S^{-\theta}$  and  $N = YP_N^{-\theta}$ .

Substitute these two quantities in the production function of the final good (2) and get:

$$Y = \left( Y^{\frac{\theta-1}{\theta}} P_S^{1-\theta} + Y^{\frac{\theta-1}{\theta}} P_N^{1-\theta} \right)^{\frac{\theta}{\theta-1}}.$$

Eliminating output on both sides, we get the following relationship between the two prices:

$$P_S^{1-\theta} + P_N^{1-\theta} = 1.$$

Next, substitute in this equation the prices from (16) and get equation (18).

### Proof of Proposition 1

We begin the proof by studying further the curve **L**, as defined by (21). We first write (21) in logarithms:

$$(A.1) \quad \ln L_S - \ln L_N + \ln v_S + \ln(1 + v_S) - \ln v_N - \ln(1 + v_N) = 2\ln(1 - f_S) - 2\ln(1 - f_N) + (f_N - f_S)(\theta - 1).$$

Note that if  $f_N$  rises, so does  $f_S$  and as  $f_N$  gets closer to 1, so does  $f_S$ , since otherwise the RHS of (A.1) goes to infinity. Hence the curve **L** is increasing and it passes through the point (1, 1), as described in Figure 1. It also follows that this curve is below 1. We next study the location and shifts of this curve.

The LHS of (21) or of (A.1) depends on  $v_N$  and  $v_S$ . These two variables depend on  $h$ , through equations (10) and (11), from which we get:

$$(A.2) \quad \frac{dv_S}{dh} = -\frac{1}{h(1-h)} \frac{v_S}{1+v_S} \quad \text{and} \quad \frac{dv_N}{dh} = -\frac{1}{h(1-h)} \frac{v_N}{1+v_N}.$$

Using (A.2), we can calculate the derivative of the LHS of (A.1) with respect to  $h$ :

$$\begin{aligned} & \frac{d}{dh} [\ln(1 + v_S) + \ln v_S - \ln(1 + v_N) - \ln v_N] = \\ & = -\frac{h}{h(1-h)} \left[ \frac{v_S}{1+v_S} \left( \frac{1}{1+v_S} + \frac{1}{v_S} \right) - \frac{v_N}{1+v_N} \left( \frac{1}{1+v_N} + \frac{1}{v_N} \right) \right] = \frac{h}{h(1-h)} \left[ \frac{1+2v_N}{(1+v_N)^2} - \frac{1+2v_S}{(1+v_S)^2} \right] > 0. \end{aligned}$$

The last inequality is because the function  $(1+2x)/(1+x)^2$  is decreasing and since  $v_S > v_N$ . Hence, as  $h$  rises, the LHS of (21) rises. This means that the curve **L** shifts downward.

As  $h$  rises, the LHS of (21) increases, and reaches its maximum at  $h = (1+b)^{-1}$ , according to constraint (6). Denote the value of  $v_N$  at this  $h$  by  $v^*$ , so the value of the LHS of (21), at any  $h$ , satisfies:

$$\frac{L_S}{L_N} \frac{v_S(1+v_S)}{v_N(1+v_N)} < \frac{L_S}{L_N} \frac{b(1+b)}{v^*(1+v^*)} < \frac{L_S}{L_N} \frac{b(1+b)}{a(1+a)} < 1.$$

The last inequality is due to constraint (7). Hence, the LHS of (21) is everywhere smaller than 1. It follows from (21) that  $f_N < f_S$  everywhere. Hence, the curve **L** lies everywhere above the diagonal. It therefore follows that the **L** curve and the **G** curve must intersect and due to their opposite slopes, their intersection point **E** is unique. This proves existence and uniqueness of the equilibrium.

As for the effect of a rise in  $h$  on the equilibrium, it shifts the **L** curve downward and thus increases  $f_N$  and reduces  $f_S$ . This proves the Proposition.

### Derivation of Equation (23):

In equilibrium all intermediate high skill goods, which are produced by labor, for  $i > f_S$ , use the same amount of effective labor, since they all face the same wage and the same price. Therefore, the amount produced of such a good is:

$$s(i) = \frac{E_S}{1 - f_S}.$$

If the intermediate good is mechanized, for  $i \leq f_S$ , the amount of capital used in its production is equal, due to equations (9) and (10), to:

$$s(i) \frac{\kappa}{1 - i} = \frac{P_S S}{\kappa R} \frac{\kappa}{1 - i} = \frac{P_S S}{R}.$$

Hence the amount of capital is equal across these intermediate goods and is equal to:  $K_S / f_S$ . As a result, the amount produced of such a mechanized intermediate good is:

$$s(i) = \frac{K_S(1 - i)}{f_S \kappa}.$$

Substituting the amounts of high skill intermediate goods produced by labor and by machines in the production function (3) we get:

$$\begin{aligned} \ln S &= \ln A + \int_0^{f_S} [\ln K_S - \ln f_S - \ln \kappa + \ln(1 - i)] di + \int_{f_S}^1 [\ln E_S - \ln(1 - f_S)] di = \\ &= \ln A + f_S \ln K_S + (1 - f_S) \ln E_S - f_S \ln f_S - f_S \ln \kappa - (1 - f_S) \ln(1 - f_S) + \int_0^{f_S} \ln(1 - i) di. \end{aligned}$$

Calculating the integral, we get equation (23).

### The Effect of Technology on Productivity

Since the two sectors are symmetric, we analyze the effect for the high skill sector. The natural logarithm of high skill productivity is:

$$\ln A_S = \ln A - f_S \ln f_S - 2(1 - f_S) \ln(1 - f_S) - f_S - f_S \kappa + (1 - f_S) \ln(1 + v_S).$$

The derivative with respect to  $f_S$  is:

$$\frac{dA_S}{df_S} = -\ln f_S + 2 \ln(1 - f_S) - \ln(1 + v_S) - \ln \kappa = \ln \frac{(1 - f_S)^2}{f_S(1 + v_S)\kappa}.$$

First,  $f_S$  should be around 1/3. The threshold for hiring,  $v_S$ , cannot be too high, assume that it is below 5. As mentioned in the paper,  $\kappa$  should be quite small, around 0.1. Under these plausible sizes of parameters and variables, we get that the derivative of  $A_S$  with respect to technology is positive. This result is even stronger for low skill productivity, since  $f_N < f_S$  and  $v_N < v_S$ .

### Effect of Labor Regulation on Ratio of Productivities

The derivative of  $\ln A_S - \ln A_N$  with respect to labor regulation  $h$  is:

$$\begin{aligned} \frac{d(\ln A_S - \ln A_N)}{dh} &= \ln \frac{(1-f_S)^2}{f_S(1+v_S)\kappa} \frac{df_S}{dh} - \ln \frac{(1-f_N)^2}{f_N(1+v_N)\kappa} \frac{df_N}{dh} - \\ &\quad - \frac{(1-f_S)v_S}{(1+v_S)^2} \frac{1}{h(1-h)} + \frac{(1-f_N)v_N}{(1+v_N)^2} \frac{1}{h(1-h)}. \end{aligned}$$

The first line describes the effect of technical change, while the second line describes the change in average labor efficiency. Note that the first line should be positive, as discussed above. As for the second line, it should be positive, since  $1-f_N > 1-f_S$ , and  $v_N(1+v_N)^{-2} > v_S(1+v_S)^{-2}$  if the thresholds are above 1. This always holds if  $a > 1$ .

### Derivation of Equations (29) and (30):

From equation (23) we derive the following way of describing productivity in the high skill sector:

$$(A.3) \quad A_S = \frac{S}{K_S^{f_S} M_S^{1-f_S}}.$$

Since  $S$  is not observed in the data we next turn to describe it by observable variables. Note that:

$$(A.4) \quad \frac{Y}{S} = \left[ 1 + \left( \frac{N}{S} \right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}.$$

From equations (16) and (17) we get:

$$\left( \frac{N}{S} \right)^{\frac{\theta-1}{\theta}} = \left( \frac{P_N}{P_S} \right)^{1-\theta} = \left[ \frac{(\kappa R / A) \exp(f_N)}{(\kappa R / A) \exp(f_S)} \right]^{1-\theta} = \exp[(f_N - f_S)(1-\theta)].$$

We next apply the equilibrium condition (21) and get:

$$\left( \frac{N}{S} \right)^{\frac{\theta-1}{\theta}} = \frac{L_N}{L_S} \frac{(1+v_N)v_N}{(1+v_S)v_S} \left( \frac{1-f_S}{1-f_N} \right)^2.$$

Using the calculation of the supplies of workers  $M$  and equation (26) of the wage ratio we get:

$$\left(\frac{N}{S}\right)^{\frac{\theta-1}{\theta}} = \frac{w_N M_N (1+v_N)v_S (1-f_S)}{w_S M_S (1+v_S)v_N (1-f_N)}.$$

Substituting in (A.4) and then in (A.3) we get:

$$(A.5) \quad A_S = \frac{Y}{K_S^{f_S} M_S^{1-f_S}} \left[ \frac{w_S M_S}{w_S M_S + w_N M_N \left( \frac{1-f_S}{1-f_N} \frac{1+1/v_N}{1+1/v_S} \right)} \right]^{\frac{\theta}{\theta-1}}.$$

Since we do not observe the variables  $f_S$ ,  $f_N$ ,  $v_S$  and  $v_N$ , equation (29) is our best approximation to (A.5). It can be shown that as  $h$  rises,  $(1+1/v_N)/(1+1/v_S)$  increases, while  $(1-f_S)/(1-f_N)$  increases as well. Hence, as  $h$  rises,  $A_S$  declines relative to (29). This means that if we observe empirically a negative effect of labor regulation on measured high skill productivity (29), the decline of the model productivity (A.5) is even larger. Similarly, the true productivity of the low skilled sector is:

$$(A.6) \quad A_N = \frac{Y}{K_N^{f_N} M_N^{1-f_N}} \left[ \frac{w_N M_N}{w_N M_N + w_S M_S \left( \frac{1-f_N}{1-f_S} \frac{1+1/v_S}{1+1/v_N} \right)} \right]^{\frac{\theta}{\theta-1}}.$$

Here an increase in  $h$  reduces  $(1+1/v_S)/(1+1/v_N)$  and  $(1-f_N)/(1-f_S)$  as well, so that (A.6) increases by more than the measured productivity (30). Hence, if the empirical tests show that labor regulation increases (30), the effect on the true variable (A.6) should be even stronger.

## Appendix B: Tables

Table B.1: Data Sources and Coverage

<b>Variable</b>	<b>Source</b>	<b>Time span</b>	<b>Countries</b>
EPL	OECD Employment Protection Legislation Database	1985-2013	44
UD and UC	ICTWSS Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts (Visser, 2013)	1960-2011	45
KRATIO	Output, Input and Productivity Measures at the Industry Level: the EU KLEMS Database, O'Mahony and Timmer (2009) ISIC 3 rev. March 2008 release	1970-2005	16
AS and AN	Computed as in Caselli and Coleman (2006) using Feenstra et al. (2015), Barro and Lee (2013) and Psacharopoulos (1994) data	1950-2010	52
HSPAT and LSPAT	W.I.P.O. World Intellectual Property Organization Database	1980-2012	100

Table B.2: Labor Regulation and Capital Ratio: Other Specifications

Explanatory Variables	Dependent variable: $\Delta$ KRATIO			Dependent variable: KRATIO		
	1	2	3	4	5	6
KRATIO_lagged				1.017*** (0.009)	1.009*** (0.005)	1.008*** (0.005)
EPL	-0.084*** (0.020)	-0.096*** (0.022)	-0.043 (0.035)	-0.101*** (0.007)	-0.090*** (0.007)	-0.093*** (0.010)
UD		-0.106 (0.079)	-0.142 (0.104)		-0.209*** (0.024)	-0.257*** (0.038)
UC			0.092 (0.080)			0.084** (0.039)
DUMMY 1991	0.152*** (0.020)	0.152*** (0.020)	0.152*** (0.020)	0.192*** (0.012)	0.142*** (0.013)	0.136*** (0.014)
R <sup>2</sup> (within)	0.30	0.31	0.28			
Wald $\chi^2$ prob.				0.000	0.000	0.000
No. of Observation	278	278	261	278	278	261
No. of Countries	15	15	15	15	15	15
1. Regressions 1-3 are fixed effects and 4-6 are SYS-GMM 2. Significance notations are *** for 1%, ** for 5% and * for 10%. 3. All columns contain year dummies						

Table B. 3: Labor Regulation and Productivities, PWT

Explanatory Variables	Dependent Variable: ln(AS)				Dependent Variable: ln(AN)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EPL	-0.431*** (0.043)	-0.396*** (0.034)	-0.421*** (0.034)	-0.260*** (0.033)	2.574*** (0.636)	2.333*** (0.605)	2.398*** (0.731)	0.217 (0.779)
UD		-1.801*** (0.099)	-1.775*** (0.142)	-0.547*** (0.174)		15.14*** (1.909)	17.50*** (3.053)	-0.484 (4.064)
UC			-0.110 (0.128)	-0.094 (0.113)			-2.250 (2.753)	-2.906 (2.638)
R <sup>2</sup>	0.15	0.49	0.48	0.62	0.03	0.13	0.11	0.24
Year dummies	N	N	N	Y	N	N	N	Y
Obs	582	559	498	498	582	559	498	498
Countries	24	23	23	23	24	23	23	23
1. All regressions contain countries fixed effects 2. Significance notations are *** for 1%, ** for 5% and * for 10%.								

Table 5a: Labor Regulation and Difference of Productivities, PWT

Dependent variable: Difference between Skilled and Unskilled productivity						
Explanatory Variables	(1)	(2)	(3)	(4)	(5)	(6)
EPL	-3.004*** (0.118)	-2.725*** (0.615)	-2.189*** (0.742)	-0.268 (0.616)	-0.877 (0.649)	-0.477 (0.788)
UD		-16.94*** (1.939)	-19.27*** (3.095)		-0.479* (0.239)	-0.063 (4.108)
UC			2.140 (2.791)			2.812 (2.666)
R <sup>2</sup> (within)	0.04	0.16	0.13	0.30	0.28	0.27
Year dummies	N	N	N	Y	Y	Y
Obs	582	559	498	582	559	498
Countries	24	23	23	24	23	23
3. All regressions contain countries fixed effects						
4. Significance notations are *** for 1%, ** for 5% and * for 10%.						