

Wage Inequality and The Effort Incentive Effects of Technological Progress*

Cecilia García-Peñalosa[†]
GREQAM and CNRS,
Marseille

Campbell Leith[‡]
Department of Economics
University of Glasgow

Chol-Won Li[§]
Department of Economics
University of Glasgow

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Abstract

This paper introduces technological progress into an efficiency wage model, and argues that changes in the rate of technical change affect not only the demand for but also the effective supply of labour. This creates a new mechanism through which technological progress impacts on the wage of skilled workers relative to that of the unskilled. Previous work has argued that an increase in the relative wage would only come about if there were an acceleration in the rate of skill-biased technological change. In contrast, we find that technical change affects the skill premium even when it is 'neutral'. Moreover, the paper shows that slower technical change may also increase the relative wage, allowing us to reconcile the change in the skill premium with the productivity slowdown experienced by OECD countries. The main problem of demand-based explanations of the increase in the skill premium is that they cannot account for the simultaneous increase in the unemployment rates for both skilled and unskilled workers. Our framework emphasises the joint determination of wages and employment, and generates wage and employment patterns that are consistent with the evidence.

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[†]Cecilia García-Peñalosa, GREQAM, Centre de la Vieille Charite, 2 rue de la Charite, 13002 Marseille, France. e-mail penalosa@ehess.cnrs-mrs.fr. García-Peñalosa would like to thank the University of Geneva for its hospitality.

[‡]Campbell Leith, Department of Economics, University of Glasgow, Adam Smith Building, Glasgow G12 8RT, UK; (Tel.) ++44-(0)141-330-3702; (Fax) ++44-(0)141-330-4940; (E-mail) c.b.leith@socsci.gla.ac.uk; (Web) <http://www.gla.ac.uk/economics/leith/>.

[§]Department of Economics, University of Glasgow, Adam Smith Building, Glasgow G12 8RT, UK; (Tel.) ++44-(0)141-330-4654; (Fax) ++44-(0)141-330-4940; (E-mail) cw.li@socsci.gla.ac.uk; (Web) <http://www.gla.ac.uk/economics/cwli/>.

1 Introduction

The recent increase in earnings inequality in a number of industrialised countries is by now a well-documented event. Countries have differed in their experiences, with the most pronounced increases taking place in the UK and the USA. The ratio of the 90th to the 10th percentile of the male wage distribution rose from 2.51 to 3.11 in the UK and from 3.26 to 4.35 in the US over the period 1980-1995.¹ An important component of this increase in inequality has been the rise in the educational wage differential. Between 1980 and 1988, the wage ratio of university graduates to workers with no qualification increased by almost 8 per cent in the UK, and the wage ratio of college to high school graduates rose by some 25 per cent in the US over the period 1979-95 (Acemoglu, 2000).

For half a decade the main explanation for the upsurge in wage inequality has been the hypothesis of an acceleration in *skill-biased technological change*. The argument that has been put forward is that the development of new information technologies has resulted in a shift in relative demand for labour in favour of those with greater skills (see Berman, Bound and Griliches, 1994). An extensive literature has subsequently tried to understand the relationship between technology and the relative demand for skilled labour.² Recent empirical work has, however, documented the importance of both international trade and changes in the supply of skills. Feenstra and Hanson (1999) show that when we measure trade by the degree of ‘outsourcing’, increased competition in the market for low-skill manufactures from newly-industrialising countries can account for a large fraction of the change in the relative wage in the US. Supply effects have been documented by Card and Lemieux (2001). Using data for the US, the UK, and Canada, they decompose the US labour force into cohorts and find that, starting with the cohorts born in

¹See OECD *Employment Outlook* (1996).

²This hypothesis has been theoretically explored by Eicher (1996), Galor and Tsiddon (1997), Greenwood and Yorukoglu (1997), Acemoglu (1998), and Caselli (1999), among others.

the 1950s, there has been a significant slowdown in the rate of growth of educational attainment that can explain the sharp increase in the premium to education for these cohorts. Still, they find that there has been an increase in the returns to education for all cohorts that cannot be explained by aggregate supply changes, and which may well be due to technological change.

The aim of this paper is two-fold. First, it contributes to the theoretical literature on the relationship between technological progress and relative wages by examining how, in the presence of imperfect information in the labour market, technical change can affect not only demand but also the *effective supply* of skills. Second, imperfect information will generate equilibrium unemployment, and will allow us to account for a fact that has largely been ignored by previous explanations of the rise in the skill premium, namely, that the increase in the relative wage has been accompanied by an increase in unemployment rates for both skilled and unskilled workers (see the discussion in section 2).

Our argument is based on the efficiency wage model of Shapiro and Stiglitz (1985), whereby imperfect information on the part of firms about whether or not employees are shirking forces the former to pay wages above the market clearing level, which in turn leads to unemployment. The combination of high wages and the risk of remaining unemployed if found shirking and fired, induces optimal effort on the part of workers. We introduce technological progress into this framework. We stress that an important feature of new technologies is that they not only create new jobs, they also destroy old ones. When an innovation arrives, some workers retain their jobs but others are reallocated between jobs or made redundant.³This process affects the effort incentives of workers, and hence the effective labour supply. That is, changes in the rate of technical change alter the trade-off between pay and unemployment that firms face, and will affect equilibrium wages and employment.

³The importance of this process has been documented by Davis and Haltiwanger (1992). They find that in the US, between one third and one half of total worker reallocation (between employers or from employment to joblessness) is due to shifts in employment opportunities across firms.

In general, the net impact of technical change on wages is ambiguous. Faster technical change increases the discounted wage flow but, since it also raises turnover, it reduces the probability of remaining with the current employer, and hence it may increase or decrease the present value of being employed. Depending on parameter values, one or the other effect will dominate. Moreover, if some of these parameters differ across types of workers, changes in the rate of technical change will affect relative effective supplies. We consider two types of workers, skilled and unskilled, and maintain that certain characteristics of the labour markets in which they operate differ. In particular, we assume that it is easier to monitor the effort levels of the unskilled and that it is easier for a skilled worker that has lost her job to immediately find a new one, as her transferable skills make her more adaptable to the new technology than an unskilled worker. These differences imply that the incentives of the two types of workers will not be affected in the same way by a change in the rate of technical progress, and that consequently the relative (effective) supply of workers will shift.

A number of results emerge. First, if technical change is biased, in the sense that it increases the demand for skilled workers relative to that for unskilled, then the incentive mechanism may strengthen or partially offset the effect of demand on relative wages. A more surprising finding is that if technical change is ‘neutral’, in the sense that it leaves the relative demand for labour unchanged, an increase or fall in the rate of technical change will still change the relative wage. In other words, *technological progress affects the skill premium even when it is skill-neutral*. Third, we find that a *reduction* in the rate of technical change can generate an increase in the skill premium. Fourth, the model generates patterns of unemployment that are consistent with the data. As we will see in detail in the next section, demand-based explanations have problems explaining the productivity slowdown and the increase in both the skilled and the unskilled unemployment rates that have been contemporaneous with the increase in relative wages. The

efficiency wage model allows us to reconcile these three facts.

This paper contributes to two recent strands in the growth literature, both of which have not received as much attention as they merit. The first one is the literature on unemployment and technological progress, pioneered by Aghion and Howitt (1994). Aghion and Howitt introduce technological progress into a search model of the labour market to examine the interaction between growth and long-term unemployment. The adoption of new technologies requires the reallocation of labour across firms, and hence determines the rate of job destruction. They show that faster technological progress has two effects on the demand for labour. By increasing the discounted flow of profits from a new job, it increases firms' incentives to post a new vacancy, and tends to raise the demand for labour. There is also a negative creative destruction effect, as faster innovation tends to reduce the expected duration of a job match, reducing the demand for labour. Parameter values then determine which of these two effects dominates. Our approach also exploits the idea that technological progress makes hiring and firing endogenous. However, instead of concentrating on the demand for labour, we focus on the supply of labour when imperfect information forces firms to pay efficiency wages in order to discipline workers.

The second related area of research is the literature on growth and imperfect information. The analysis of information asymmetries in growth models has almost exclusively focused on the role of capital market imperfections.⁴ Although labour economists have long emphasized the importance of imperfect information in understanding the workings of the labour market, its implications for macroeconomic outcomes have seldom been explored. An exception is the work of Eicher and Kalaitzidakis (1997) and Eicher (1999) (see also Kalaitzidakis, 1996). These papers examine a setup in which workers need to be trained to use a particular technology. The training costs to firms are decreasing in the worker's ability, but firms have imperfect information about

⁴See, for example, Zeira (1991) and Tsiddon (1992).

an applicant's ability. As a result there is an adverse selection problem whereby a reduction in the wage reduces the quality of the applicant pool. The implications of introducing adverse selection in the labour market for an open-economy growth model are striking: there will be informational efficiency gains from trade that can lead to a reduction in the income gap between trading partners. We explore a very different type of informational asymmetry, yet our approach also emphasises that the fact that firms need to pay efficiency wages has important implications at the aggregate level.

The paper proceeds as follows. Section 2 discusses the existing literature on technical change and the skill premium, and argues that there are a number of empirical regularities that they have difficulty in explaining. Section 3 outlines the model and considers the incentive effects of technological progress. We show that there are two effects working in opposite directions, and examine the impact of a change in the rate of technological progress on wages and employment in a particular labour market. Section 4 then uses the model to analyse the impact of technical progress on the skill-premium. We find that both skill-biased and skill-neutral technological progress affect the relative wage. We then show how our framework can generate a simultaneous increase in the relative wage and in the unemployment rates of both types of workers. Policy implications are discussed in section 6, while section 7 concludes.

2 Biased Technical Change, Demand, and the Increase in Relative Wages

The early empirical literature on the increase in relative wages found little support for the role of supply or international trade as potential explanations.⁵Theoretical work has consequently concentrated on modelling the way in which new technologies shift the relative demand for

⁵See Murphy and Welch (1992) and Berman, Bound, and Griliches (1994).

labour. This literature has, however, encountered three problems when trying to fit the evidence. The first one is the productivity slowdown. The 1970s and 1980s witnessed a sharp reduction in rates of total factor productivity growth, with TFP growth in the US falling from 3% in the mid-1960s to around 1% by the late 1980s. The UK, France, and Germany experienced even sharper declines over the period.⁶ Yet most work on wages and technical change relies on an *increase* in the rate of technological progress. The reason is that this approach is based on the hypothesis, first put forward by Nelson and Phelps (1966), that the main difference between educated and non-educated workers is the greater capacity of the former to absorb and implement new technologies. The relative demand for skilled labour will then only increase if there is faster technical change that forces firms to employ more educated individuals needed to implement the new technologies.

Critics of the skill-biased technical change explanation have argued that it is not consistent with the productivity slowdown observed during the 1970s and 1980s. Several counterarguments have been put forward to reconcile faster technical change with slower productivity growth. For example, Howitt (1998) highlights the measurement problems associated with standard measures of total factor productivity based on residual calculations from aggregate output data. The most common approach has, however, been the argument that the implementation of a new technology induces a temporary productivity slowdown. The reasons may be that it takes time to learn to use the new technology, that implementation involves diverting resources into the risky experimentation of the new technology, or that during the phase of implementation there is a reduction in the concentration of high-ability workers in the technologically advanced sectors, which diminishes the likelihood of further technological breakthroughs (see Greenwood and Yorukoglu, 1997; Aghion and Howitt, 1998, chapter 8; and Galor and Tsiddon, 1997,

⁶See OECD Economic Outlook (2001)

respectively). Yet, productivity has fallen over a 20 year period, which seems a rather long experimentation period. A major concern of our paper is hence whether it is possible for the skill premium to increase when the rate of technical change itself falls.

One of the few explanations of the increase in the relative demand for skilled workers that does not require faster technological change has been put forward by Acemoglu (1998). He argues that researchers can target their effort to innovations that complement either skilled or unskilled labour. Because of the increase in the supply of educated workers in the 1960s, technical change *became* skill-biased, and the wage ratio started to increase even though there was no change in the aggregate rate of productivity growth. We build on the idea that innovations are targeted to one or other type of workers. More specifically, we assume that some goods are produced only with skilled labour and others with only unskilled labour. The number of goods produced by each type of worker increases over time, but they may increase at different rates. This means that the rate of technological change in the two sectors can differ. In this scenario, a slowdown in unskilled-oriented technical change would make technical change more biased towards the skill, while reducing the average rate of productivity growth in the economy. We could then witness a simultaneous increase in the skill premium and a reduction in TFP. Moreover, in our framework a slowdown can increase the relative wage even if technical change is neutral (i.e. if the number of goods in both sectors grows at the same rate). As we have argued before, differences in the skilled and unskilled labour markets imply that they are not equally affected by changes in the speed of technical change. It is then possible for an overall slowdown to reduce both wages, but reduce those of the unskilled by more, leading to a higher skill premium.

The second problem of the skill-biased technical change hypothesis is the evidence of a sharp reduction in the real wage of low-skill workers in the US over the 1980s. Between 1980 and 1989, the real wage of the lowest decile of the earning distribution fell by 11% in the US (OECD

Employment Outlook, 1993). This can be easily reconciled with the hypothesis that increased trade has caused the change in relative wages, yet it is difficult to explain how faster technical change -even if skill-biased- would reduce the marginal product of unskilled workers.⁷ Two recent papers have provided possible explanations. Caselli (1999) considers a set up in which, following a technological breakthrough, new and old machines are simultaneously in use. Workers with high (low) skills use the new (old) machines. Since the rate of return on capital has to be equalised across all types of machines, there is an increase (reduction) in the capital-labour ratio for new (old) machines. Low-skilled workers are now operating with less capital, and hence their marginal product falls. Galor and Moav (2000) explore the idea that if the lowly educated have technology specific skills, while the highly educated have general skills, faster technical change makes some of the skills of former obsolete, and consequently reduces their level productivity (see also Eicher and García-Peñalosa, 2001). The efficiency wage model examined in this paper provides an alternative explanation for the reduction in real wages, namely that because the rate of growth affects the incentives of workers to shirk, it impacts on the *level* of wages that firms have to pay in order to extract optimal effort from their labour force.

Lastly, the demand-based explanations have difficulties accounting for the shifts in employment experienced by OECD countries. As we can see in table 1, the increase in the skill-premium has indeed been greatest in the US and the UK, with rather modest changes in Italy, Germany and Sweden. This raises the question of why is it that changes that should have affected all industrial economies in roughly the same way, have not had similar effects on relative wages. The standard explanation has been the following. Technological change and/or trade, have shifted the relative demand for skilled workers in OECD countries. In the US and the UK, flexible labour markets permitted an adjustment of wages and resulted in the observed increase in the

⁷See Acemoglu (2000) on this critique.

relative wage. In Europe, wage rigidities maintained the skill premium constant; employment had to adjust, leading to an increase in unskilled unemployment.

Table 1 around here

However, as it was first pointed out by Nickell and Bell (1995, 1996), the above argument does not fit the data. First, as we can see in table 2, unemployment rates were much higher in the 1980s than in the 1970s for both skilled and unskilled workers. This increase in unemployment took place in both the North American and the European economies. Second, the relative wages of the unskilled have fallen in the UK and the US, while they have stayed constant in Germany. Yet, unskilled unemployment rates are similar in Germany and the US, and much higher in the UK. The demand-based explanations are incapable of accounting for the simultaneous shift in relative wages and the increase in unemployment for both types of workers. Our framework provides a possible explanation. The efficiency wage model implies that there is equilibrium unemployment in all labour markets. Moreover, changes in the rate of technical change will affect both wages and employment. In this context it is possible that a decline in the rate of technological progress increases both the skilled and unskilled wage, and reduces the level of employment for both types of workers. If the skilled wage increases by more, we can simultaneously observe a higher skill premium and greater rates of unemployment for both types of workers.

Table 2 around here

To sum up, the hypothesis that the increase in the skill premium has been due to faster skill-biased technological progress finds it difficult to account for the contemporaneous productivity slowdown, the fall in the unskilled real wage in the US, and the increase in unemployment rates

for both high-education and low-education workers. Using a supply-side approach based on the efficiency-wage model we are capable of providing a framework in which all these variables can move in a way consistent with the evidence.

3 The Model

3.1 Features of the Economy

Workers

Time is continuous and denoted by t . There are H skilled and L unskilled workers, and $E_i(t)$ and $U_i(t)$, $i = H, L$ denote the number of workers employed and unemployed, respectively. This means $H = E_H(t) + U_H(t)$ and $L = E_L(t) + U_L(t)$. We assume that H and L are fixed and do not allow for their endogenous determination. As regards preferences, all workers are identical in that they are risk-neutral and the intertemporal utility function is time-additive. This implies that the real rate of interest is given by the rate of time preference, ρ , which is common to all consumers. We assume that agents consume all their labour income, $w_i(t)$, $i = H, L$, as they receive it. They also decide whether or not to exert effort when employed. The instantaneous utility function when employed is $w_i(t) - \varepsilon T_i(t)$, $i = H, L$, where $\varepsilon T_i(t)$ is the disutility of effort and ε can take values either 0 or 1. $T_i(t)$ is an index of the level of technology which is specific to each type of worker since, as we will see below, skilled and unskilled workers operate different technologies. This means that the cost of effort differs across the two types of workers.

Jobs can be terminated due to technological progress. For simplicity, we assume that technological progress is the only way in which workers are separated from firms in equilibrium. There is a probability η_i , $i = H, L$ that a worker immediately finds a job elsewhere following a technological innovation which destroys her job. This assumption captures, in a simple way, the observation of Davis and Haltiwanger (1992) that job-to-job reallocation of workers in the US

represents a substantial fraction of worker turnover. In what follows we assume $\eta_H \geq \eta_L$, that is, that the rate of job-to-job reallocation is at least as large for skilled as for unskilled workers, reflecting the idea that the former have more transferable skills that make them more able to deal with new technologies.

The return to a worker from being employed and not shirking, denoted by $V_i^N(t)$, is defined by the following ‘asset’ equation:

$$\rho V_i^N(t) = w_i(t) - \varepsilon T_i(t) + b_i(t) [V_i^U(t) - V_i^N(t)] + \dot{V}_i^N(t), \quad i = H, L \quad (1)$$

where $V_i^U(t)$ is the value of being unemployed. This equation says that the interest rate ρ times asset value $V_i^N(t)$ equals the flow benefits of being an employed non-shirker. The flow benefits consist of the real wage $w_i(t)$, the disutility cost of effort, $\varepsilon T_i(t)$, and capital gains/losses. The rate of worker dislocation, $b_i(t)$, is endogenous and as we will see below results from the fact that technological progress destroys jobs. This then determines whether or not the worker suffers the capital loss associated with moving from a state of employment to unemployment, $V_i^U(t) - V_i^N(t)$. The final term, $\dot{V}_i^N(t)$, captures the capital gains/losses arising from changes in wages due to the productivity effects of technical progress and the dynamics of employment adjustment.

The value of being an employed shirker, denoted by $V_i^S(t)$, follows a similar recursive equation,

$$\rho V_i^S(t) = w_i(t) + [b_i(t) + s_i] [V_i^U(t) - V_i^S(t)] + \dot{V}_i^S(t), \quad i = H, L, \quad (2)$$

where the probability of entering the state of unemployment is increased by s_i , the probability of being found shirking. This probability is specific to each category of worker and, in line with the literature on worker monitoring, we assume that $s_L > s_H$.

The value of being unemployed is given by the following recursive equation

$$\rho V_i^U(t) = zT_i(t) + a_i(t) [V_i^N(t) - V_i^U(t)] + \dot{V}_i^U(t), \quad i = H, L. \quad (3)$$

$zT_i(t)$ denotes the opportunity cost of employment, including unemployment benefit. Since in equilibrium no worker shirks, the only way the worker can re-enter employment is if an innovation creates new jobs. The rate at which workers of type i are selected from the pool of unemployed to enter employment is given by $a_i(t)$.

Since the effort is costly, firms need to ensure that workers do not shirk, which requires $V_i^N = V_i^S$. Equating (1) and (2) gives

$$v_i^N - v_i^U = \frac{\varepsilon}{s_i} \quad (4)$$

where $v_i^U \equiv V_i^U/T_i$ and $v_i^N \equiv V_i^N/T_i$ are the productivity-adjusted values of being unemployed and employed respectively. Equation (4) in turn implies

$$\dot{v}_i^N = \dot{v}_i^U, \quad i = H, L. \quad (5)$$

Production

There is a continuum of firms with measure one. The economy produces N varieties of final goods, indexed by j . Aggregate output is then given by

$$Y = \int_0^N P(j)Q(j)dj, \quad (6)$$

where $Q(j)$ is the amount of good j produced, and $P(j)$ its price. We assume that we are in a small open economy. All goods are internationally traded, their prices being determined in world markets and hence exogenously given.

A particular variety is produced by one type of labour only. Let n_H be the number of varieties produced by skilled workers and n_L the number produced by unskilled workers, with

$N = n_L + n_H$. Supposing that all unskilled-produced goods have the same price, P_L , and that all skill-produced varieties have price P_H , we can write aggregate output as

$$Y = \int_0^{n_L} P_L Q_L(j) dj + \int_0^{n_H} Q_H(n_L + j) dj, \quad (7)$$

where the price of skilled-produced goods has been normalised to 1.

The production of final goods takes place according to a Cobb-Douglas technology in which only labour is used,

$$Q_L(j) = x_L^\alpha(j) = x_L^\alpha, \quad (8)$$

$$Q_H(j) = x_H^\alpha(j) = x_H^\alpha, \quad (9)$$

where $0 < \alpha < 1$, and $x(j)$ is employment in the production of good j . Firms maximize profits by equating the marginal product of labour to the real wage, which implies the inverse labour demand functions

$$w_i = \frac{\alpha P_i}{x_i^{1-\alpha}}. \quad (10)$$

We define our index of technical progress as $T_i = n_i^{1-\alpha}$, and let $\omega_i \equiv w_i/T_i$ denote the productivity-adjusted wage. We can then express the demand functions as

$$\omega_i = \frac{\alpha P_i}{(n_i x_i)^{1-\alpha}} \quad (11)$$

$$= \frac{\alpha P_i}{E_i^{1-\alpha}}. \quad (12)$$

where $E_i = n_i x_i$ is total employment of type i workers.

Technical Change

Technical change is exogenous, and takes the form of expanding variety. The rate of growth of unskilled-produced and skilled-produced varieties are, respectively,

$$g_L = \frac{\dot{n}_L}{n_L} \quad \text{and} \quad g_H = \frac{\dot{n}_H}{n_H}. \quad (13)$$

In what follows we are going to examine how technological progress affects relative wages and employment. Since most of the literature on the increase of relative wages has been concerned with the shift in demand due to skill-biased technical change, we make the following definitions:

- Technical change is neutral whenever $g_H = g_L = g$.
- Technical change is skill-biased whenever $g_H > g_L$.
- Technical change is de-skilling whenever $g_H < g_L$.

To understand these definitions, consider for a moment the relative demand for labour. From equation (12) we have

$$\begin{aligned} \frac{E_{Ht}}{E_{Lt}} &= \left(\frac{w_{Lt}/P_{Lt}}{w_{Ht}} \right)^{1-\alpha} \frac{n_{Ht}}{n_{Lt}} \\ &= \left(\frac{w_{Lt}/P_{Lt}}{w_{Ht}} \right)^{1-\alpha} \frac{n_{H0}}{n_{L0}} e^{(g_H - g_L)t}, \end{aligned} \quad (14)$$

where n_{i0} is the initial number of type i varieties. When the rate of growth of the two types of varieties is the same, the two labour demand functions shift proportionally, leaving the relative demand for skills unchanged. This is what we term neutral technical change. A faster rate of growth of skill-produced varieties implies that the relative demand for skills increases over time, i.e. results in skill-biased technical change, while for $g_H < g_L$ the relative demand falls as technology improves.

3.2 The Incentive Effects of Technological Progress

Labour Reallocation

A salient feature of technological progress is that new jobs are created as old jobs are destroyed. To understand how these effects work in our model, consider the labour demand functions (11). The number of workers used to produce a given variety depends on the number

of varieties of intermediate goods and on the equilibrium wage. Log-differentiating equation (11) and using (13) we obtain

$$-\dot{x}_i = x_i \left(g_i + \frac{1}{1-\alpha} \frac{\dot{\omega}_i}{\omega_i} \right). \quad (15)$$

The left-hand side is the number of jobs lost in a given variety in a unit time interval. The right-hand side shows that the number of jobs lost is proportional to the number of jobs that existed with a coefficient determined by the rate of increase in real wages and by the rate of technological progress. If all workers who are separated from firms could not find jobs elsewhere, $-\dot{x}_i$ would be equivalent to the number of individuals becoming unemployed in a given variety. However, recall that we have assumed that a fraction η_i of workers who are separated from firms are immediately recruited by a new firm. Therefore, the number of workers joining the unemployment pool from a given variety is $-(1-\eta_i)\dot{x}_i$, and the probability of a given worker becoming unemployed is $b_i = -(1-\eta_i)\dot{x}_i/x_i$. We then have

$$\begin{aligned} b_i &= (1-\eta_i) \left(g_i + \frac{1}{1-\alpha} \frac{\dot{\omega}_i}{\omega_i} \right) \\ &= (1-\eta_i) \left(g_i - \frac{\dot{E}_i}{E_i} \right). \end{aligned} \quad (16)$$

When employment E_i is constant, the probability of becoming unemployed is simply $b_i = (1-\eta_i)g_i$.

The number of workers becoming unemployed in a given variety during time interval dt is given by $x_i b_i dt$, hence $n_i b_i x_i dt$ is the total number of workers of type i becoming unemployed in an economy as a whole. The number of unemployed workers who find jobs is $a_i U_i dt$. Therefore, changes in employment during time interval dt are $\dot{E}_i dt = (a_i U_i - n_i x_i b_i) dt$, which gives, upon rearrangement,

$$a_i = \frac{\eta_i \dot{E}_i + (1-\eta_i) g_i E_i}{U_i}. \quad (17)$$

Incentive Effects

We can now examine the impact of technological progress on workers' effort incentives and its effect on the wage-employment trade-off. Firms ensure that workers do not shirk by setting $V_i^N = V_i^S$, which using equations (1) and (2) can be solved for productivity adjusted wages ω_i .

The resulting individual no-shirking condition (*NSC*) is

$$\omega_i = [\rho - (1 - \alpha) \overset{(i)}{\downarrow} g_i] \left(v_i^U + \frac{\varepsilon}{s_i} \right) + \varepsilon + (1 - \eta_i) \overset{(ii)}{\downarrow} \frac{g_i - \dot{E}_i/E_i}{s_i} \varepsilon - \dot{v}_i^N, \quad (18)$$

where v_i^U is to be determined. In fact, equations (1) to (5) imply

$$v_i^U = \frac{z + \frac{\varepsilon}{s_i} \cdot \frac{\eta_i \dot{E}_i + (1 - \eta_i) \overset{(iv)}{\downarrow} g_i E_i}{U_i} + \dot{v}_i^U}{\rho - (1 - \alpha) \overset{(iii)}{\uparrow} g_i}. \quad (19)$$

These two equations together determine the combinations of wages and unemployment that ensure that workers do not shirk. Before obtaining the equilibrium *NSC* it is worth examining in detail the incentive effects of technical change. Equation (18) gives the combinations of ω_i and E_i that ensure no shirking (for given v_i^U), and shows that this trade-off is affected by the rate of technical change. First, consider the term indicated by (i). Technological progress results in increased returns to employment, implying that workers lose more if they are found to be shirking. It therefore tends to strengthen the disciplinary effect of unemployment, allowing firms to reduce the wage for a given level of employment. We call this the *employment capitalization* effect of productivity growth. It is analogous to what Aghion and Howitt (1994) call the capitalization effect of growth on labour demand, which increases the return of creating a new job and makes it profitable for firms to hire more workers.

The second effect, indicated by (ii), is what we call the *job destruction effect*. Recall that $b_i = (1 - \eta_i) \left(g_i - \dot{E}_i/E_i \right)$ is the probability of a worker becoming unemployed, and its inverse, $1/b_i$, is the average duration of employment. As g_i increases, employment duration falls, weakening

the disciplinary effect of unemployment. Firms are consequently required to raise ω_i in order to extract effort from workers. Note that the strength of the job destruction effect depends on the extent of job-to-job reallocation. If the latter is high, the expected duration of employment is long, and the impact of job destruction weakens.

Technical change also affects the employment-wage trade-off through v_i^U , as the greater the value of being unemployed, the higher the wage needed to induce no shirking is. From equation (19), a higher g_i reduces the effective discount rate at which consumers capitalize future benefits as unemployed, and makes unemployment a more attractive option. We call this the *unemployment capitalization effect* of productivity growth. Because this effect increases v_i^U , it tends to raise ω_i . The last effect is indicated by (iv) in (19). It operates through the job-acquisition rate a_i , which as we saw in equation (17) is a function of the rate of technical change. Its inverse $1/a_i$ is the average duration of unemployment. As g_i rises, duration falls and the disciplinary effect of unemployment weakens. This is termed the *job creation effect* of technological progress. Note that as *more* jobs are created, real wages rise. This prediction sharply contrasts with studies of technological unemployment arising from the demand side, in which more job creation results in greater employment and lower wages (see, for example, Aghion and Howitt, 1994).

Our assumption that the rate of detection of shirkers is less than infinity implies that firms need to use a combination of higher wages and unemployment to provide workers with sufficient incentives not to shirk. Using (5), equations (18) and (19) can be rearranged into

$$\dot{E}_i = E_i \frac{(\omega_i - z) \frac{s_i}{\varepsilon} + \left[(1 - \alpha) - \frac{(1 - \eta_i) i}{i - E_i} \right] g_i - \rho - s_i}{1 + \frac{\eta_i i}{i - E_i}}. \quad (20)$$

In steady state, where $\dot{E}_i = 0$, this condition reduces to

$$\omega_i = z + \varepsilon + \frac{\varepsilon}{s_i} \left[\rho - (1 - \alpha) g_i + \frac{(1 - \eta_i)}{1 - E_i/i} g_i \right]. \quad (21)$$

The steady state *NSC* implies an upward-sloping relationship between the wage and the level of employment. The wage is equal to the unemployment benefit plus the cost of effort plus a term that captures the incentive effects. The four effects we discussed above are in fact combined into two effects. The term $(\rho - (1 - \alpha) g_i)$ is the effective discount rate, and captures the employment and unemployment capitalization effects. These two effects move in opposite directions. Yet since the steady-state flow benefits from unemployment are necessarily less than the flow benefits from employment,⁸ the unemployment capitalization effect will be less than the employment capitalization effect, and the overall effect on wages is negative. The job destruction and job creation effects are also combined in a single term capturing the probabilities of entering and exiting unemployment, since $a_i + b_i = (1 - \eta_i) g_i / (1 - E_i/i)$. Both effects imply that faster technical change tends to reduce the value of not shirking, and hence tend to increase the wage. Clearly, η_i plays a crucial role in determining the strength of the job creation-destruction effect. A very high value, would make it impossible for firms to use unemployment as a disciplinary mechanism, as when workers get fired they would hardly ever become unemployed.

Equation (21) reveals that there are two basic competing tendencies determining the impact of growth on effort incentives. On the one hand, a higher g_i reduces the effective discount rate, as the growth in real wages caused by technological progress raises the value of employment relative to unemployment and reduces the incentives to shirk. On the other, the reallocation of workers induced by technical progress increases job turnover, implying that workers have less incentive to avoid shirking as they are more likely to lose their jobs for other causes. Either of these two effects may dominate.

⁸If the flow benefits of employment were not greater than the flow benefits when unemployed, then there would be no disciplining effect from unemployment, and it would be impossible to prevent shirking.

3.3 Equilibrium and Comparative Statics

The equilibrium wage and employment level are then given by the intersection of the demand function with the steady state *NSC*, given, respectively, by the following expressions:

$$\omega_i = \frac{\alpha P_i}{E_i^{1-\alpha}}, \quad (DD)$$

$$\omega_i = z + \varepsilon + \frac{\varepsilon}{s_i} \rho + \frac{\varepsilon}{s_i} \left[\frac{1 - \eta_i}{1 - E_i/i} - (1 - \alpha) \right] g_i. \quad (NSC)$$

As depicted in Figure 1, the demand function is monotonically decreasing and the *NSC* monotonically increasing, implying a unique equilibrium, (E_i^*, ω_i^*) . Note from equation (20) that whenever the wage is greater than ω_i^* , then $\dot{E}_i > 0$, while for $\omega_i < \omega_i^*$, $\dot{E}_i < 0$. This implies that the equilibrium is stable, with firms moving along the demand function until the equilibrium is reached.⁹

We can now examine the effect of a number of parameters on the equilibrium. Consider first the impact of technological change. Differentiating the steady state *NSC* with respect to g_i yields

$$\frac{d\omega_i}{dg_i} \begin{cases} > 0 & \text{for } E_i > \widehat{E}_i \\ = 0 & \text{for } E_i = \widehat{E}_i \\ < 0 & \text{for } E_i < \widehat{E}_i \end{cases} \quad \text{where } \widehat{E}_i = \frac{\eta_i - \alpha}{1 - \alpha} i < i. \quad (22)$$

Whether a change in g increases or decreases the productivity-adjusted wage depends on the equilibrium level of employment relative to a critical value, \widehat{E}_i . Figure 2 illustrates the case of a reduction in the rate of technological change. A lower value of g pivots the *NSC* curve around \widehat{E}_i , from the solid to the dotted curve. If employment is initially above \widehat{E}_i , then the wage falls and employment rises following a slowdown in the rate of technical change, while if employment is initially below \widehat{E}_i a lower g_i decreases ω_i and increases E_i . The intuition for this results is

⁹See Georges (1994) for a proof that this gradual employment adjustment is the unique equilibrium of the Shapiro-Stiglitz model.

simple. We have seen that technological progress creates two types of effort incentive effects, the capitalization effect and the job creation-destruction effect. For high levels of employment, the latter effect is strong as it implies a short duration of unemployment. Therefore any slowdown in productivity growth reduces job turnover, reduces the incentives to shirk and allows firms to reduce the non-shirking real wage. When employment is low, the capitalization effect dominates, and the wage rises after a decrease in g_i .

Note that the job-to-job reallocation rate plays a crucial role in shaping the relationship between technological progress and wages, as it determines the threshold level of employment \widehat{E}_i . For a given level of employment, the larger η_i is, the weaker the job creation-destruction effect is, and hence the more likely it is that an increase in the rate of technical change reduces the equilibrium wage (i.e. the more likely it is that E_i is below \widehat{E}_i).

The rest of the comparative statics are straight-forward. A higher cost of effort shifts upwards the *NSC*, increasing the wage and reducing employment; while an increase in either the probability of being caught shirking, the rate or job-to-job reallocation, or the supply of labour tends to reduce the wage and raise employment.

Lastly, consider a shift in the demand function caused by an decrease in the price of the good produced by type- i workers. A lower P_i shifts the demand function leftward, resulting in a lower equilibrium wage and level of employment, as see in figure 3. The long-run equilibrium moves from B_1 to B_3 . However, in the short-run the economy moves to B_2 with ω_i^2 undershooting its equilibrium value, ω_i^* . Profit maximizing behaviour on the part of firms implies that they will remain on their labour demand curves at all points in time, while in the short-run they can lie off the steady-state no-shirking condition. The reason for this is that as firms attempt to reduce the size of their workforce, the increased hire rate has a positive effect on the effort incentives of their employees. This means that firms can reduce the wages they offer and still maintain

effort levels. As the hire rate returns to the steady-state level, wages must be raised, and the economy moves along the new demand curve until it reaches the new steady-state equilibrium. That is, the NSC implies that there will be undershooting of wages in response to a decrease in the demand for labour (and correspondingly overshooting in response to an increase in demand).

4 Relative Wages

Having obtained the equilibrium in each of the two labour markets, we are now in a position to examine the effect of technical change on the skill premium. Let $\Omega_t \equiv w_{Ht}/w_{Lt}$ be the relative wage at time t . From our production function we can express it as

$$\begin{aligned}\Omega_t &= \frac{\omega_{Ht} \cdot n_{Ht}^{1-\alpha}}{\omega_{Lt} \cdot n_{Lt}^{1-\alpha}} \\ &= \frac{\omega_{Ht}}{\omega_{Lt}} \left(\frac{n_{H0}}{n_{L0}} \right)^{1-\alpha} e^{(1-\alpha)(g_H - g_L)t},\end{aligned}\tag{23}$$

or using the demand functions (12), as

$$\Omega_t = \left(\frac{n_{H0}}{n_{L0}} \right)^{1-\alpha} \left(\frac{E_{Lt}}{E_{Ht}} \right)^{1-\alpha} \frac{1}{P_{Lt}} e^{(1-\alpha)(g_H - g_L)t}.\tag{24}$$

In the absence of incentive effects, the levels of employment are simply equal to the supplies of the two types of labour, that is, $E_{Lt} = L$ and $E_{Ht} = H$.¹⁰ Equation (24) then encompasses the three hypotheses that have been put forward to explain the recent increase in the skill premium: the relative supply of skills, H_t/L_t ; the effect of international trade, captured by a change in the relative price of unskilled-produced goods P_{Lt} ; and skill-biased technical change, as reflected by the difference in the rate of innovation of the two types of goods, $g_H - g_L$.

Introducing incentive considerations implies that wages will depart from their market-clearing levels, and adds an alternative mechanism through which technological progress can affect relative wages. There are two important ways in which the supply-side effect differs from the

¹⁰We are implicitly assuming that the unemployment benefit is below the wage that would clear the market. Otherwise, $E_{it} = (\alpha P_i/z)^{1-\alpha}$ and there would be unemployment.

above demand-driven impact of technical change. First, in contrast to the existing literature, an increase in the skill premium can be consistent with a *reduction* in the rate of technological change. Second, as we will see below, technical change may increase the skill premium even if it is *neutral*.

4.1 Biased Technical Change and the Productivity Slowdown

That skill-biased technical change increases the relative wage in our model will come as no surprise. Still, it is worth examining how the supply-side effects interact with the standard demand-side impact. Because of the importance of the productivity slowdown during the 1980s, let us consider the effect of a fall in the rate of technological change. Suppose, more precisely, that we start in a situation of neutral technical change, with $g_L = g_H$, and that there is a reduction in g_L to g'_L , while g_H remains constant. That is, technological progress becomes skill-biased.

The economy experiences a productivity slowdown. To see this, differentiate the production function and use the fact that, in steady state, $\dot{x}_i/x_i = -g_i$ to express the rate of output growth as

$$\frac{\dot{Y}}{Y} = (1 - \alpha) (\theta g_H + (1 - \theta) g_L),$$

where θ is the share of output produced by skilled workers, $\theta = n_H Q_H / (n_L P_L Q_L + n_H Q_H)$. In steady state, since employment does not change, output growth is equivalent to productivity growth, and the change in g_L lowers the rate of productivity growth from $(1 - \alpha) g_H$ to $(1 - \alpha) (\theta g_H + (1 - \theta) g'_L)$.

Consider now what happens to wages. The skilled labour market remains unchanged, employment remains constant and the real wages of skilled workers keep growing at rate $(1 - \alpha) g_H$. In the unskilled labour market, the NSC pivots. As we saw before, two situations are possible.

If the initial level of employment is above the threshold \widehat{E}_L , then the productivity adjusted wage ω_L falls in response to the change in g_L . Both the ratio ω_H/ω_L and the extent of skill-bias in demand, as measured by $(g_H - g_L)$, increase and by equation (23) so does the relative wage. In this case, the supply-side effect magnifies the increase in relative wages stemming from the demand for labour. If the initial level of employment is below the threshold \widehat{E}_L , then ω_L will rise. The ratio ω_H/ω_L will fall, implying that the presence of incentive effects partly offsets the demand-led increase in the relative wage.

Note that for $E_L > \widehat{E}_L$, the real unskilled wage, $w_{Lt} = \omega_L(n_{L0})^{1-\alpha}e^{(1-\alpha)g_L t}$, may actually fall when g_L falls. If the fall in g_L is large enough, then the reduction in the productivity adjusted wage could, for a period of time, offset the effect of improving productivity.¹¹ Under this scenario, we would simultaneously have an increase in the skill premium, a productivity slowdown, and a reduction in the real unskilled wage.

4.2 Neutral Technical Change

Suppose now that the two types of varieties increase at the same rate, $g_H = g_L = g$, and that there is a reduction in the rate of technical change. What would be the impact on the relative wage? We can see from equation (23) that there is no demand effect as the demand for both types of workers shifts proportionally. The only impact stems from the impact of a lower g on the productivity-adjusted wages.

Consider the ratio of the productivity-adjusted wages, ω_H/ω_L . Differentiating we have

$$\frac{d(\omega_H/\omega_L)}{dg} = \frac{1}{\omega_L} \left[\frac{d\omega_H}{dg} - \frac{\omega_H}{\omega_L} \frac{d\omega_L}{dg} \right]. \quad (25)$$

where

$$\frac{d\omega_i}{dg} = \frac{(1-\alpha)(E_i - \widehat{E}_i)}{\frac{s_i(i-E_i)}{\varepsilon} + \frac{1-\eta_i}{1-\alpha} \frac{g}{\omega_i} \frac{iE_i}{i-\widehat{E}_i}}.$$

¹¹For example, the unskilled wage would definitely fall if g_L dropped to zero.

The first thing to note in equation (25) is that *neutral technical change is not neutral*. The reason for this is that it affects differently the effort incentives of the two types of workers and hence elicits different wage responses on the part of firms. The impact of technical change on the relative wage is in principle ambiguous. The cause of this ambiguity is twofold. First, as we saw in section 4, slower technological progress may increase or decrease productivity-adjusted wages depending on whether the capitalization or the job creation-destruction effect dominates. Second, knowing the sign of the change in ω_L and ω_H is not sufficient, as both can move in the same direction implying that we also need to know their magnitude.

Two parameters differ across the two labour markets and hence allow us to pinpoint some of the circumstances under which neutral technical change will unambiguously increase or decrease the skill premium. Suppose first that $s_L = \infty$. Substituting for it in equation (25) we have

$$\frac{\partial(\omega_H/\omega_L)}{\partial g} = \frac{1}{\omega_L} \frac{E_H - \widehat{E}_H}{\frac{s_H}{\varepsilon} \frac{H-E_H}{1-\alpha} + (1-\eta_H) \frac{g}{\omega_H} \frac{HE_H}{H-E_H}}. \quad (26)$$

Slower neutral technical change decreases the relative wage for $E_H > \widehat{E}_H$, and increases it otherwise. The intuition for this result is straightforward. Because shirking is immediately detected, there is no need to use a high wage as a disciplinary mechanism. Firms will simply compensate workers for the cost of effort, and pay them $\omega_L = z + \varepsilon$. The unskilled wage is consequently independent of the rate of technical change. A fall in g then increases the relative wage if and only if it increases the skilled productivity-adjusted wage.

A second parameter of interest is the extent of job-to-job reallocation. Job-to-job reallocation is important because it determines the strength of the job creation-destruction effect of technical change and hence whether it increases or decreases wages. Consider the extreme case in which $\eta_L = \alpha$ and $\eta_H = 1$; that is skilled workers who are fired immediately find a new job, while unskilled workers always enter the unemployment pool. Then we have that $\widehat{E}_L = 0$ and $\widehat{E}_H = H$, and equation (25) implies

$$\frac{\partial(\omega_H/\omega_L)}{\partial g} = -\frac{1-\alpha}{\omega_L} \left[\frac{H-E_H}{\frac{s_H(H-E_H)}{\varepsilon} + \frac{1}{1-\alpha} \frac{g}{\omega_H} \frac{HE_H}{H-E_H}} + \frac{\omega_H}{\omega_L} \frac{E_L}{\frac{s_L(L-E_L)}{\varepsilon} + \frac{g}{\omega_L} \frac{LE_L}{L-E_L}} \right] < 0. \quad (27)$$

A high value of η_H implies that the job creation-destruction effect disappears in the skilled labour market. Slower technical change has only a capitalization effect, which increases the equilibrium skilled wage. In the unskilled labour market, low reallocation makes the job creation-destruction effect dominate, resulting in a lower unskilled wage. That is, ω_H increases and ω_L falls, leading to a higher skill premium.

4.3 Calibration

In order to look at possible patterns of wage inequality following a reduction in the rate of neutral technical change, we calibrate the model and obtain numerical examples. Recall that the equilibrium of the model is given by the intersection of the following curves:

$$\begin{aligned} \omega_i &= \frac{\alpha A P_i}{E_i^{1-\alpha}}, \\ \omega_i &= z + \varepsilon + \frac{\varepsilon}{s_i} \rho + \frac{\varepsilon}{s_i} \left[\frac{1-\eta_i}{1-E_i} - (1-\alpha) \right] g_i, \end{aligned}$$

where A is a scale parameter in the production function introduced in order to get reasonable values for wages and employment, and the skilled and unskilled labour forces have been normalised to 1. We choose the following parameter values:

| | |
|---|--------------------------------------|
| Preferences: $\rho = 0.04, \varepsilon = 1$ | Labour market: $L = 1, H = 1, z = 0$ |
| Technology: $\alpha = 0.6, A = 4.1$ | $s_H = 0.02, s_L = 0.2$ |
| Prices: $P_H = 1, P_L = 0.66$ | $\eta_H = 0.99, \eta_L = 0.75$ |

The values of ρ and α are standard, corresponding to a rate of time preference of 4% and an elasticity of labour of 60%. The cost of effort and the scale parameter A have been arbitrarily chosen. The price of the skill-produced good is used as a numeraire, and it is assumed to be 50% higher than that of the unskilled good in world markets. There are no unemployment benefits. The probability of a shirker being caught is assumed to be 10 times as large for unskilled than for skilled workers, reflecting the idea that monitoring those performing menial tasks is much easier.

The choice of job-to-job reallocation parameters is not obvious, as the evidence is sparse. Evidence on transfers following job destruction suggests that in Germany 32% of all separations result in re-employment within one week, and in Canada 53% of workers were in a new job within 3 weeks.¹² Because we are using annual values in the calibrations, the corresponding rates of job-to-job reallocation should be much higher. We can obtain an indirect estimate from the evidence presented by Davis and Haltiwanger (1992). They find that, in the US, total worker reallocation in a year -i.e. the proportion of workers that change employers or transit from employment to joblessness during a year- was 36.8% over the period the 1972-86. We can then use the unemployment rates to proxy which proportion of those separated from an employer have another job within a year. During this period the unemployment rates for high-education and low-education workers were 2% and 7.8%, respectively.¹³ The flow into unemployment of type i workers can be expressed as

$$f_i = 0.368 * E_i(1 - \eta_i), \quad (28)$$

assuming the same reallocation rate for skilled and unskilled workers. If the flow were equal to the stock, i.e. all those unemployed would find a job within the year, the implied job-to-job reallocation rates would be 0.944 and 0.77 for skilled and unskilled workers, respectively. Of

¹²See OECD (1996).

¹³See Nickell and Bell (1996). These are unemployment rates for the period 1971-82.

course, not all workers do find a job within a year, implying that these figures provide only a lower bound. Supposing that only 10% of those unemployed find a job within the period, the corresponding rates would be $\eta_H = 0.9944$ and $\eta_L = 0.9770$. We can view these numbers as lower and upper bounds for our proxy. In our benchmark calibration we use the values $\eta_H = 0.99$ and $\eta_L = 0.75$, representing the greatest difference between the two categories of workers implied by these estimations. We will then perform comparative statics on them.

The above parameters are used to obtain values for the benchmark economy, depicted in the first three columns of table 3. We consider the effect of a reduction in the rate of productivity growth from 5% to 1% on the benchmark economy. We can see that a reduction in g , increases ω_H and reduces ω_L . The productivity slowdown thus results in an increase in the skill premium accompanied by a reduction in the real unskilled wage. These results depend strongly on the degree of job-to-job reallocation for the skilled. Table 3 shows that as η_H changes we obtain a number of different patterns.¹⁴ For high values of η_H , e.g. $\eta_H = 0.99$ and $\eta_H = 0.95$, the reduction in the rate of technical change increases the skill premium. For $\eta_H = 0.8$, both the skilled and the unskilled wage fall with g . In this particular case, the two wages change proportionally and the skill premium is unaffected by the productivity slowdown. For an even lower rate of job-to-job reallocation, $\eta_H = 0.75$, the skilled wage falls by more, leading to a reduction in the skill premium. In other words, a reduction in the rate of neutral technological change may increase, decrease, or keep constant the skill premium depending on the rate of job-to-job reallocation for skilled workers.

Tables 3, 4, 5 around here

¹⁴Note that the unskilled wage is only reported once, as it does not depend on η_H .

Table 4 reports the results from a similar exercise for η_L . In this case, the unskilled wage decreases as g falls for all values of η_L , leading to an increase in the wage ratio. Lastly, table 5 examines the effects of different probabilities of being caught shirking. The higher the probability is, the smaller the impact of a fall in the rate on technical change on the skill premium. A high s_L implies a flatter *NSC* curve (i.e. a weaker trade-off between wages and unemployment), and consequently the fall in g results in a small wage change. As we saw above, in the extreme case in which unskilled shirkers are found with certainty, the only effect of a lower growth rate on the relative wage would come from the increase in the skilled wage.

5 The Wage-Employment Puzzle

As we have already argued, one of the problems of existing explanations of the increase in relative wages is that they have difficulties accounting for the increases in unemployment rates for both skilled and unskilled workers during the 1980s. In contrast, our framework can generate a simultaneous increase in the wage premium and in unemployment for both types of workers. There are in fact several circumstances under which this may happen. One possibility is that the changes in employment and wages are only due to a technological slowdown. Suppose that we are in a situation in which $E_H < \widehat{E}_H$ and $E_L < \widehat{E}_L$. A reduction in the rate of technical change will pivot the *NSC* in the two labour markets, leading to an increase in the productivity-adjusted wages and a reduction of employment levels in both markets. If the skilled wage increases more sharply than the unskilled wage, then the skill premium and unemployment rates will increase together.

However, as we have already argued, there is strong evidence supporting both the role of increased competition in the market for low-skill manufactures from newly industrialising countries and of changes in relative labour supplies in explaining the increase in the skill premium.

In this section we argue that a reduction in the rate of neutral technological progress, together with either of these two effects can simultaneously generate the observed changes in employment and relative wages.

Consider the following scenario. Suppose that η_H is large and η_L is small, so that we are initially in an equilibrium where $E_H < \hat{E}_H$ and $E_L > \hat{E}_L$. A reduction in the rate of technical change will pivot the NSC in the two labour markets. For skilled workers, the job creation-destruction is weak, and the fall in g will have the effect of increasing the productivity-adjusted wages and reducing employment levels. In the unskilled market, the opposite will happen, ω_L falls and E_L . As we saw in subsection 5.1, the reduction in the productivity-adjusted wage may well result in a lower real unskilled wage. Suppose that at the same time there is a fall in P_L , which will shift downwards the demand function in the unskilled labour market. As we can see in figure 4, if the demand shift is sufficiently large this will result in a fall in unskilled employment. That is, the combination of the productivity slowdown and the reduction in the world price of low-skill manufactures, resulted in an increase in the skill premium and an increase in both skilled and unskilled unemployment. The reasons for the increase in unemployment are, however, different in the two labour markets. Skilled employment falls because the strength of the job creation-destruction requires disciplining workers through unemployment, while unskilled unemployment is the direct effect of a lower price for their output.

Figure 4 around here

Alternatively, we could think of a situation in which the slowdown in the rate of technical change is accompanied by an increase in the supply of unskilled workers, that is, by a fall in the relative supply of skills.¹⁵The increase in the supply of unskilled labour will tend to reduce the

¹⁵This is a simplified version of the argument in Card and Lemieux (2001), where the supply effects stem from a slowdown in the rate of growth of the relative supply of skills, rather than a fall in the relative supply.

unskilled wage, reinforcing the effect of slower technical change. The effect on unemployment is in principle ambiguous, as both the unskilled labour force and the level of employment are now higher. As we will see in our calibrations, it is in fact possible for the unemployment rate to rise. The intuition for this is simply that since a greater supply tends to depress the wage, firms need to compensate the resulting weakening of incentives with an increase in unemployment in order to prevent shirking. It is usually argued that an increase in the relative supply of unskilled workers results in *either* higher relative wages *or* greater unskilled unemployment, depending on whether wages are flexible or not. In an imperfect information set up, both the relative wage and unskilled unemployment will change.

To illustrate these effects, we calibrate the model to match US data. Productivity growth in the US fell from 3% to 1% between 1970 and 1990. We choose parameters so that such a reduction in g together with a fall in the price of the unskilled good replicate that the data on unemployment and the skill premium. We fix the following parameters: $\alpha, \rho, z, \varepsilon, P_H$, and s_L , and let the data determine the rest. This yields

| | | | |
|--------------|--------------------------------|----------------|--|
| Preferences: | $\rho = 0.04, \varepsilon = 1$ | Labour market: | $L = 1, H = 1, z = 0$ |
| Technology: | $\alpha = 0.6, A = 3.038715$ | | $s_H = 0.04494404, s_L = 0.7$ |
| Prices: | $P_H = 1, P_L = 0.6601476$ | | $\eta_H = 0.99458087, \eta_L = 0.743499$ |

Table 6 reports the results. The first row replicates the situation in 1970, with a skill premium of 1.49 and low rates of unemployment rates of 1.7 and 5.27 for skilled and unskilled workers, respectively.¹⁶The second row considers the effect on wages and employment of a fall

¹⁶The unemployment figures differ slightly from those reported in table 2. The latter are averages over the period 1971-82. Instead, we use observations for the average unemployment rates over the period 1971-74 from Nickell and Bell (1995).

in the price of the unskilled-produced good from $P_L = 0.6601476$ to $P'_L = 0.56786$. (i.e. by 16%). This change captures a demand shift caused by increased international trade. Such a shift, in combination with the slowdown in productivity growth, can reproduce the fall in the wage and the increase in unemployment experienced by unskilled workers. As we argued before, under the assumption of a high job-to-job reallocation rate, slower technical progress increases the skilled wage and unemployment rate. The lower reallocation rate for the unskilled implies that the productivity slowdown partly offsets the increase in unskilled unemployment, while it reinforces the increase in the skill premium, as we can see in the third row of table 6. The table shows that a demand shift due to increased import penetration together with a fall in the rate of (neutral) technical progress can account for the simultaneous increase in the skill premium and the unemployment rates for both educated and non-educated workers.

Table 6 about here

The last two rows of table 6 consider the impact of a fall in the relative supply of skills. We first examine what happens when there is only an increase in the relative supply of unskilled labour, from $L = 1$ to $L = 1.45$. Both the relative wage and unskilled unemployment increase. The last row of the table shows the combined effect of a fall in the relative supply of skills and a deceleration of technical change: unemployment rates increase for both types of workers while relative wages rise by even more due to the incentive effects captured by our model.

6 Policy Analysis

One of the questions that the demand-based explanations have not been very good at answering has been why the US and continental Europe have had such different experiences. As we saw, the argument that labour markets are more rigid in Europe than in the US does not suffice to

explain the greater shift in unemployment and the smaller increase in relative wages observed in Europe. In this section we argue that labour market policies can indeed help explain the above differences, although we need the more complex depiction of the labour market used in this paper.

A common argument is that a major difference between the US and European labour markets is the level of unemployment benefits. In the late 1980s, benefit replacement ratios were 12% in the US, 19% in the UK, and 28% in both Germany and Sweden (OECD, 1994). In our model, benefit replacement ratios, captured by the parameter z , play an important role in determining the position of the NSC curve relative to the demand curve, and hence the magnitude of the impact of changes in other parameters. The next table considers an economy identical to that in table 6, except that the unemployment benefit is now greater. In the first two rows we consider a situation where $z = 0.05$ (rather than 0, as in our simulated US economy), and examine what happens to wages and employment as the rate of productivity growth falls from 3% to 1%, and the price of unskilled-produced goods drops from 0.660 to 0.568. The initial relative wage is still 1.49. However, following the shocks, the economy exhibits a smaller relative wage (1.67 rather than 1.70), but a greater increase in the unemployment rates of both types of workers. Rows 3 and 4 consider an economy with an even higher replacement ratio, $z = 0.12$, and show that following the shocks there is an even smaller increase in the skill premium (11% compared to 14% in the simulated US economy) and a greater increase in unemployment rates.

Table 7 around here

In section 4.3 we saw that a crucial parameter determining the effect of changes in the rate technical progress is the job-to-job reallocation rate. Although it has received little attention in international comparisons of labour market, a recent study by Boeri (1999), finds evidence

that there is more job-to-job reallocation in Europe than in the US. This, in turn, is reflected in smaller flows into and out of unemployment in Europe, even if unemployment rates are higher. His argument is that this is the result of tighter labour protection regulation in Europe which creates an ‘intermediate’ labour market status between employment and unemployment. In other words, workers that are about to be fired can remain in their jobs for a period of time which will give them the chance of finding a new position, thus moving from one job to another without an unemployment spell in between. In the US, weak employment protection implies that workers enter unemployment as soon as they are given notice of termination.

To explore the importance of this effects, the last two rows of table 7 consider an economy with a higher benefit replacement ratio, $z = 0.12$, and a higher job-to-job reallocation rate for unskilled workers, $\eta_L = 0.90$, than our calibrated US economy. This change implies that in response to the technology and price shock there is an even weaker increase in the relative wage and an even greater increase in unemployment than in the previous case. If we compare this economy with the one in table 6, the differences are large: the skill premium increases by 9% rather than 14%, while the skilled and unskilled unemployment rates rise by 289% and 359%, respectively, rather than by 65% and 95%.¹⁷

7 Conclusions

In contrast to most of the literature linking inequality and technical progress, this paper shifts the emphasis to the supply side, arguing that in the presence of imperfect information in the labour market, technical change can affect not only demand but also the effective supply of labour.

Our argument is based on the efficiency wage model of Shapiro and Stiglitz (1985), whereby

¹⁷The results obtained with $z = 0$ and $\eta_L = 0.90$, also indicate a smaller increase in the relative wage and higher change in unemployment rates than for the economy of tabel 6. We do not report the figures as the resulting unemployment rates are absurdly high.

imperfect information on the part of firms about whether or not employees are shirking forces the former to pay wages above the market clearing level, which in turn leads to unemployment. We introduced technical progress into this framework and this allowed us to endogenise the labour reallocation flows within the Shapiro-Stiglitz efficiency-wage framework. Since technical progress is responsible for the destruction of old and the creation of new jobs, technical progress impacts on workers' decisions regarding the level of effort they choose to provide. The combination of wages and employment that firms offer to ensure workers provide optimal levels of effort will, consequently, change.

The net impact of technical change on wages is, in general, ambiguous. Faster technical change increases the discounted wage flow (capitalisation effect) but, since it also raises turnover, it reduces the probability of remaining with the same employer (job creation-destruction effect), and it hence may increase or decrease the present value of being employed. Depending on parameter values, one or the other effect will dominate.

In order to examine the relationship between technological progress and relative wages, we consider two types of workers, skilled or educated and unskilled or non-educated. We have argued that there are two differences in the labour markets in which they operate. On the one hand, it is easier to monitor the effort levels of the unskilled than of the skilled. On the other, because educated workers have more transferable skills, it is easier for a skilled worker that has lost her job to immediately find a new one. That is, the rate of job-to-job reallocation is higher for skilled individuals. These differences imply that the incentives of the two types of workers will not be affected in the same way by a change in the rate of technical progress, and that consequently the relative effective supply of labour will shift.

Previous work has argued that an increase in the relative wage would only come about if there were an acceleration in the rate of skill-biased technological change. In the efficiency wage

model this is not necessarily the case. First, in this set up even if technical change is ‘neutral’, in the sense that it leaves the relative demand for labour unchanged, changes in the rate of technical progress will affect the relative wage. In other words, *technological progress affects the skill premium even when it is skill-neutral*. The reason for this is that differences in labour market parameters imply that technological progress does not shift proportionally the effective supply curves, and hence wages will not change proportionally. Second, we find that a *reduction* in the rate of technical change can generate an increase in the skill premium. Whenever the job creation-destruction effect dominates the capitalisation effect, a slowdown of the rate of technical change will tend to increase wages. If the skilled wage increases by more, the relative wage will rise.

A novel implication of our model is that it generates simultaneous changes in wages and employment. One of the problems of the demand-based explanations is that they cannot account for the simultaneous increase in the relative wage and in the unemployment rates for both skilled and unskilled workers: if the relative demand for skills has risen, why should we observe increases in skilled unemployment? Our setup can account for these patterns. The efficiency wage model implies that there is equilibrium unemployment in all labour markets. Moreover, changes in the rate of technical change will affect both wages and employment. In this context it is possible that a decline in the rate of technological progress increases both the skilled and unskilled wage, and reduces the level of employment for both types of workers. If the skilled wage increases by more, we can simultaneously observe a higher skill premium and greater rates of unemployment for both types of workers. Furthermore, the impact of a given deceleration on wages and employment depends on a number of model parameters, among them the unemployment benefit and the job-to-job reallocation rate. We find that higher values of these parameters lead to a smaller wage change and a stronger employment shift, providing a

possible explanation of the different experiences observed in the US and Europe.

An important question remains, namely the role of risk aversion in determining wages. Our conjecture is that risk aversion would raise the cost of unemployment, such that the job flows induced by technological change would have an even greater impact on inequality through the channels described in this paper.

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Table 1: Ratio of wages of high- to low-education group

| Country | Early 1970s | Early 1980s | Late 1980s | Mid 1990s |
|---------|-------------|-------------|------------|-----------|
| US | 1.49 | 1.36 | 1.51 | 1.70 |
| UK | 1.64 | 1.53 | 1.65 | |
| Canada | 1.65 | 1.39 | 1.42 | |
| Italy | 1.96 | 1.60 | 1.61 | |
| Germany | n.a. | 1.36 | 1.42 | |
| Sweden | 1.40 | 1.16 | 1.19 | |

Source: OECD Employment Outlook 1993, Table 5.6 and Acemoglu (2000).

Table 2: Unemployment Rates by Skill Category

| Country | | 1971-82 | 1983-90 | 1991-93 |
|---------|----------------|---------|---------|---------|
| US | High education | 2.0 | 2.4 | 3.0 |
| | Low education | 7.8 | 11.3 | 11.0 |
| UK | High education | 2.4 | 4.4 | 6.2 |
| | Low education | 7.5 | 15.9 | 17.1 |
| Canada | High education | 2.5 | 3.9 | 5.1 |
| | Low education | 8.3 | 11.9 | 16.1 |
| Italy | High education | 12.2 | 13.1 | 12.5 |
| | Low education | 4.6 | 7.3 | 7.5 |
| Germany | High education | 1.7 | 3.1 | 2.2 |
| | Low education | 6.4 | 13.0 | 10.7 |
| Sweden | High education | 1.0 | 1.1 | 2.8 |
| | Low education | 2.9 | 3.3 | 6.9 |

Table 3: Changes in η_H

| | $\eta_H = 0.99$ | | | $\eta_H = 0.95$ | | $\eta_H = 0.8$ | | $\eta_H = 0.75$ | |
|------------|-----------------|-------------|---------------------|-----------------|---------------------|----------------|---------------------|-----------------|---------------------|
| | ω_H | ω_L | ω_H/ω_L | ω_H | ω_H/ω_L | ω_H | ω_H/ω_L | ω_H | ω_H/ω_L |
| $g = 0.05$ | 2.51 | 1.70 | 1.48 | 2.67 | 1.57 | 3.14 | 1.85 | 3.25 | 1.91 |
| $g = 0.03$ | 2.56 | 1.67 | 1.53 | 2.73 | 1.63 | 3.09 | 1.85 | 3.19 | 1.90 |
| $g = 0.01$ | 2.82 | 1.64 | 1.72 | 2.88 | 1.75 | 3.04 | 1.85 | 3.09 | 1.88 |

Table 4: Changes in η_L

| | $\eta_L = 0.75$ | | | $\eta_L = 0.8$ | | $\eta_L = 0.99$ | |
|------------|-----------------|-------------|---------------------|----------------|---------------------|-----------------|---------------------|
| | ω_H | ω_L | ω_H/ω_L | ω_L | ω_H/ω_L | ω_L | ω_H/ω_L |
| $g = 0.05$ | 2.67 | 1.70 | 1.57 | 1.68 | 1.49 | 1.63 | 1.54 |
| $g = 0.03$ | 2.73 | 1.67 | 1.63 | 1.66 | 1.54 | 1.62 | 1.57 |
| $g = 0.01$ | 2.88 | 1.64 | 1.75 | 1.64 | 1.72 | 1.62 | 1.73 |

Table 5: Changes in s_L

| | $s_L = 0.1$ | | $s_L = 0.2$ | | | $s_L = 0.7$ | |
|------------|-------------|---------------------|-------------|-------------|---------------------|-------------|---------------------|
| | ω_L | ω_H/ω_L | ω_H | ω_L | ω_H/ω_L | ω_L | ω_H/ω_L |
| $g = 0.05$ | 1.79 | 1.40 | 2.51 | 1.70 | 1.48 | 1.64 | 1.53 |
| $g = 0.03$ | 1.74 | 1.47 | 2.56 | 1.67 | 1.53 | 1.63 | 1.57 |
| $g = 0.01$ | 1.68 | 1.68 | 2.82 | 1.64 | 1.72 | 1.63 | 1.73 |

Table 6: Simulating Unemployment and Wages in the US

| | ω_H | $1-E_H/H$ | ω_L | $1-E_L/L$ | ω_H/ω_L |
|--|--------------|------------|--------------|-------------|---------------------|
| $g = 0.03,$ $P_L = 0.660, L = 1$ | 1.836 | 1.7 | 1.232 | 5.27 | 1.49 |
| $g = 0.03,$ $P_L = 0.568, L = 1$ | 1.836 | 1.7 | 1.109 | 15.85 | 1.65 |
| $g = 0.01,$ $P_L = 0.568, L = 1$ | 1.844 | 2.8 | 1.085 | 11.00 | 1.70 |
| $g = 0.03,$ $P_L = 0.660, L = 1.45$ | 1.836 | 1.7 | 1.110 | 15.65 | 1.65 |
| $g = 0.01,$ $P_L = 0.660, L = 1.45$ | 1.844 | 2.8 | 1.085 | 10.76 | 1.70 |

Table 7: Changes in Unemployment Benefits and Job-to-Job Reallocation

| Labour market parameters | Technical change and prices | ω_H | $1-E_H$ | ω_L | $1-E_L$ | ω_H/ω_L |
|-----------------------------------|-----------------------------|------------|---------|------------|---------|---------------------|
| $z = 0.05$ $\eta_L = 0.743499$ | $g = 0.03, P_L = 0.660$ | 1.839 | 2.2 | 1.240 | 7.3 | 1.49 |
| | $g = 0.01, P_L = 0.568$ | 1.870 | 6.2 | 1.121 | 18.1 | 1.67 |
| $z = 0.12$ $\eta_L = 0.743499$ | $g = 0.03, P_L = 0.660$ | 1.849 | 3.42 | 1.260 | 10.9 | 1.47 |
| | $g = 0.01, P_L = 0.568$ | 1.930 | 13.3 | 1.180 | 28.5 | 1.63 |
| $z = 0.12$ $\eta_L = 0.90$ | $g = 0.03, P_L = 0.660$ | 1.849 | 3.42 | 1.233 | 5.9 | 1.50 |
| | $g = 0.01, P_L = 0.568$ | 1.930 | 13.3 | 1.175 | 27.1 | 1.63 |

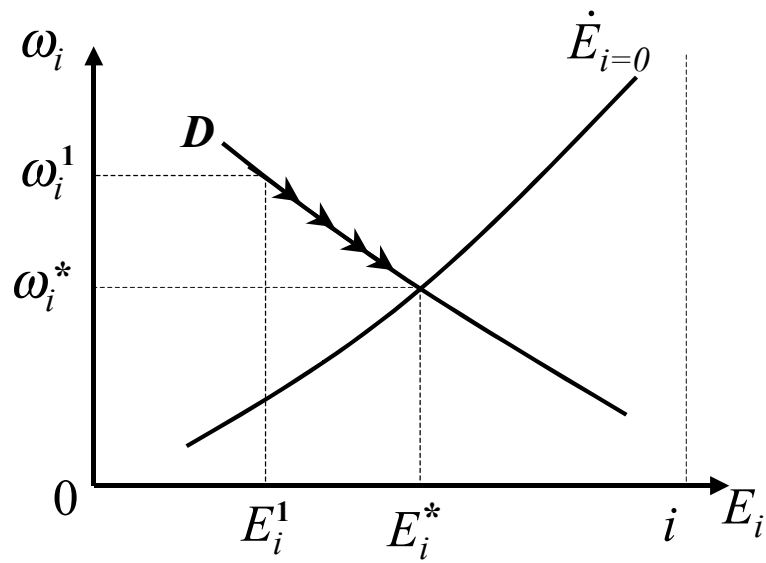


Figure 1 - Equilibrium in the Labour Market

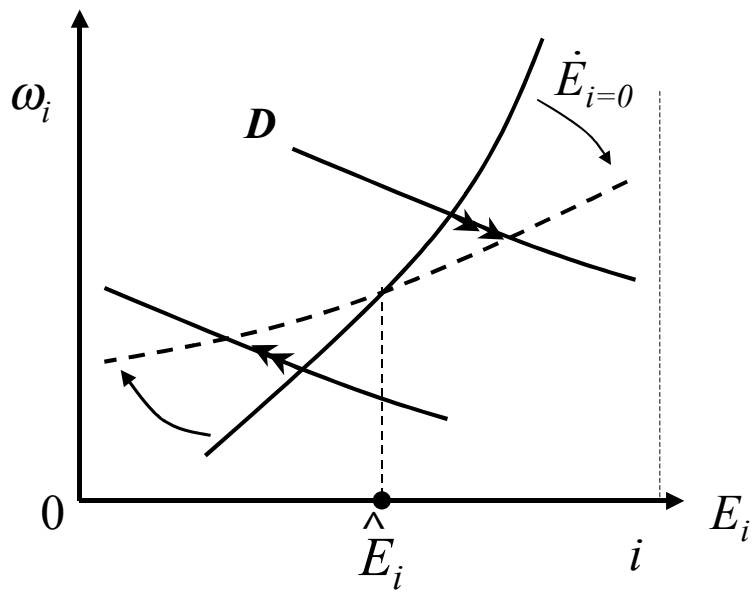


Figure 2 - The Impact of a Productivity Slowdown

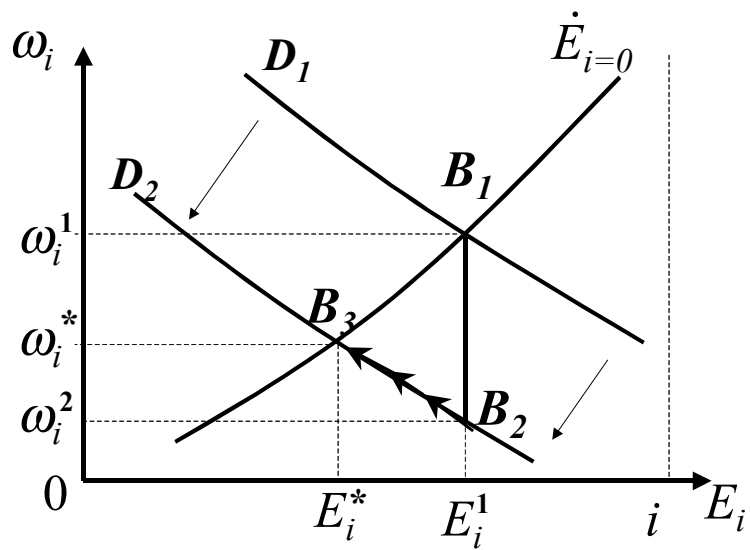


Figure 3 - A Decrease in the Price of Tradeables

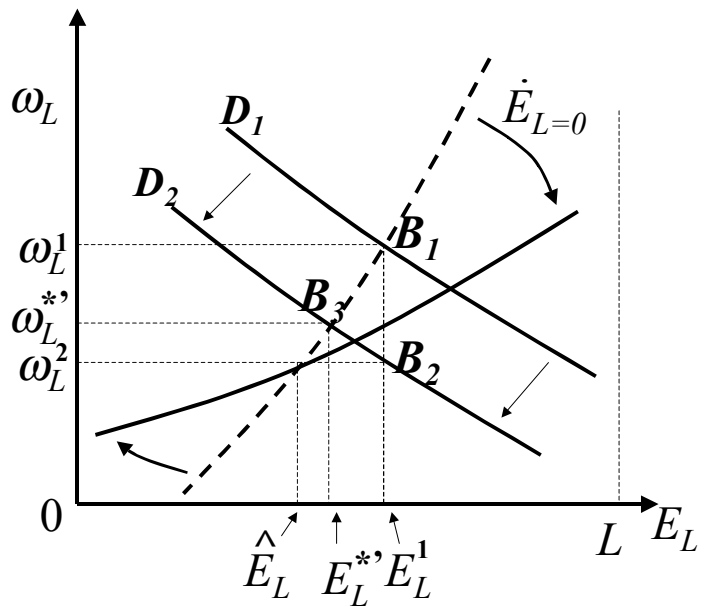


Figure 4 - The Unskilled Labour Market