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Abstract

To explain the rise in the college wage premium in developed economies in the past decades, the present paper examines the effects of technological progress on workers' effort incentives, which determine the effective labor supply. Five effort incentive effects of technological progress are identified, and through these we obtain a number of results. Firstly, we establish that wage inequality can increase following an acceleration in skill-neutral technological progress. Secondly, an increase in skill-biased technological progress means, (i) skilled wages overshoot, (ii) unskilled wages undershoot, and hence (iii) wage inequality overshoots their respective long-run values. Thirdly, endogenising the number of skilled and unskilled workers on the basis of economic incentives does not eliminate wage inequality even in the long run. Fourthly, we can obtain hysteresis effects in the determination of long-run wage inequality. Finally, government policies which raise the equilibrium rate of unemployment are likely to reduce the impact of technical progress on inequality, and this may help to explain the relative increase in inequality in the US and UK compared with other European economies. Our focus on the supply-side complements studies which emphasize the impact of skill-biased technological progress on relative demand for skill workers.

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1 Introduction

A sharp rise in wage inequality among workers with different educational backgrounds has been observed in many developed economies in the last few decades. For example, Acemoglu (2000) reports that the college wage premium in the US has risen by more than 25% between 1979 and 1995, while the ratio of the supply of skilled labour to unskilled labour had risen almost fourfold over the same period. This is often taken to suggest that there has been an increase in the relative demand for skilled workers over this period which has outstripped the increase in relative supply.

To explain trends of this type, theoretical studies emphasize the impact of skill-biased technological progress on relative demand, motivated by the recent surge in the use of computers and computer-assisted technologies. For example, Krusell, *et al.* (2000) and Maoz and Moav (2000) stress the complementarity of physical capital and skill. Another class of models, e.g. Aghion, *et al.* (2000), Caselli (1999), Galor and Maov (2000) and Galor and Tsiddon (1997) use the insight that skilled workers may be more able to adapt to new technologies. These studies basically attribute shifts in relative demand for skilled workers to an acceleration of skill-biased technological progress. Interesting insights are also offered by Acemoglu (1998, 1999) who argues that increases in relative supply stimulates the relative demand for skills through "induced" technological progress and changes in the composition of jobs offered by firms. Note that these studies stress the impact of technological progress on relative labor *demand*.

While these explanations are plausible, the present paper shifts the emphasis away from the labor-demand-side effects of skill-biased technical progress, turning, instead, to the impact of technical change on labor *supply*. We argue that focusing on the demand side tells only half the story. Our study on the supply side attempts to provide the other half of the technology-inequality link. In this sense, the present paper complements the studies which highlight the demand-side story of skill-biased technological progress.

Technological progress affects the labour supply in a number of ways. More efficient birth control methods and labour-saving equipment in households may have increased women's labor participation. Long-distance work became possible due to the development of new transport technologies, and revolutionary information and communication technologies expanded the border of local, or even national, labour markets. Although these developments are certainly important, we put aside these aspects. Instead, our study is more narrowly focused on the *effective* supply of labour in terms of workers' effort.

To highlight our argument in a familiar framework, we develop a model based on the efficiency wage model of Shapiro and Stiglitz (1985). In doing so, we stress an important feature of technological progress. That is, new technologies not only create new jobs, they also destroy old jobs. An obvious consequence is that although some workers will retain their jobs, many others are reallocated between jobs or made redundant. This whole process affects the effort incentives of workers,and hence the effective labor supply.[1] Further, such effort incentive effects of technological progress differ depending on types of workers. For example, skilled workers are less vulnerable to labor reallocation than unskilled workers because, for example, their transferrable skills make them more adaptable to new technologies.[2] Knowing that new technologies are more (less) likely to reallocate unskilled (skilled) workers, different types of workers respond differently to skill-biased technological progress, and these differing responses give rise to increasing wage inequality for a given relative labor demand.

By incorporating productivity growth and job turnover arising from technical progress, we are able to identify five effects running from rapid technical progress to workers' effort incentives.

[1] This job reallocation mechanism is stressed in many studies on unemployment and technological progress. A pioneering study is Aghion and Howitt (1994).

[2] Davis, *et al.* (1996, Table 3.4, p.44) show that the rate of job reallocation is higher for low-paid workers. This point will be discussed further below.

In general, the net impact of technological progress on the wages of skilled and unskilled workers via these incentive effects is ambiguous. However, we argue that certain characteristics of the labour market (e.g. vulnerability to labor reallocation) make it likely that an acceleration in technical progress, *even when it is skill-neutral*, can increase inequality.

We also demonstrate that an economy where policy induces a high equilibrium rate of unemployment is less likely to suffer from technological progress induced wage inequality relative to an economy with fewer frictions. We argue that this may partially account for the less pronounced increase in inequality in European economies such as France relative to the experience of the UK or US.

Perhaps, a more interesting result concerns the short-run *overshooting* of wage inequality following an increse in skill bias. That is, wage inequality in the short-run rises by more than the increase in inequality in the long-run. This arises from a combination of the overshooting of skilled wages and the undershooting of unskilled wages as an increased skill bias weakens the worker descipline effect of unemployment for skilled workers but strengthens it for unskilled workers, and these effects are more pronounced in the short run. An obvious implication is that wage inequality can be very volatile due to transitory effects. This finding accords with an empirical regularity that large increases in transitory as well as permanent components of earnings variation contributed to the rise in cross-sectional earning inequality in the US (see Katz and Autor (1999, pp.1493-7)). Our model offers a possible explanation for the rise in earnings instability.

Another question the present paper attempts to answer concerns the long-run response of wage inequality to skill-biased technological progress. If the skill premium is high,this may encourage people to undertake the education necessary to become a skilled worker, thereby increasing the relative supply of skilled workers and reducing inequality. To what extent will this supply side response mitigate the recently observed increase in inequality?

We, therefore, extend our basic model to allow for the possibility that there are interactions between the relative demand and (effective) supply curves. We make the assumption is that people choose to become skilled through costly education. Not surprisingly, this mitigates wage inequality. However, wage inequality does not fully return to its original level following an increase in skill-biased technical change due to "diminishing returns to education." Intuitively, more able individuals (i.e. those for whom it is less costly to obtain an education) choose to gain skills first, and then less able individuals follow. This means that an increase in the relative demand for skills requires less able individuals to become skilled in equilibrium. However, less able individuals in turn require a higher return from being skilled to compensate for the higher cost of gaining skills through education. This prevents wage inequality from falling back to its initial value. The third extension is to introduce a positive externality running from the number of skilled workers in employment to the cost of training - the idea is that when the skilled workforce is large, the education system will be geared towards the attainment of skills, and the costs to an individual of gaining skills will, therefore, be lower. An interesting result that emerges from this analysis is the existence of hysteresis in wage inequality. That is, the economy can tend towards either a high or low level of wage inequality in the long run, depending on the initial level of skilled employment.

The paper proceeds as follows. Section 2 gives a brief overview of the empirical literature relating trends in inequality to skill-biased technical progress. We also discuss some stylised facts relating to the differing characteristics of skilled and unskilled labour markets, as these will underpin our arguments surrounding the net impact of technical progress on workers' effort incentives. Section 3 outlines our model and identifies five ways in which technical progress can impinge on workers' effort incentives. Section 4 then uses the model to analyze the impact of technical progress, both with and without skill-bias, on inequality. Policy implications are also discussed. Section 5 then extends the model to consider wage inequality in the long-run by endogenising the proportion of skilled and unskilled workers. Section 6 concludes.

2 A Brief Review of Empirical Findings

A key stylized fact running through the literature on inequality is that after falling sharply in the 1970s, the college wage premium has been rising since then in almost all OECD countries. For details of these trends for a small selection of OECD economies see Table 1. This increase in the college wage premium in the 1980s and 1990s (see Acemoglu (2000)) has, however, been associated with a clear increase in the relative supply of skilled workers. Table 2 gives some detail of the trends during the 1970s and 1980s.While the increase in the relative supply of college graduates can help explain the decline in the college wage premium in the 1970s, its continued expansion in the 1980s (and 1990s - see Acemoglu *op. cit.*) led many authors to conclude that there must be a rapid increase in relative demand for skilled workers. In particular, skill-biased technical progress (broadly interpreted) is widely regarded as a main factor behind the increase in relative demand.

There are two hypotheses as to the impact of this skill-biased technical change - the 'steady-demand' and the 'accelerationist' hypotheses, respectively. The steady-demand hypothesis argues that over the last thirty years there has been a steady increase in relative demand for skilled workers. It emphasises relative supply moving at a different rate from the steady drift in relative demand as an important factor of changes in the college wage premium. Studies which support the steady demand hypothesis include Katz and Murphy (1992), Murphy, Riddle and Romer (1998) and Card and Lemieux (2000). Accelerationists, on the other hand, argue that the shift in demand towards skilled workers has been taking place at an accelerated rate. The acceleration hypothesis is supported by, e.g. Krueger (1993), Berman, Bound and Griliches (1994), Autor, Katz and Krueger (1998).[3] According to these studies, wage inequality rose largely because of a shift in the relative demand for college workers especially in the 1980s.

Another key fact that must be explained is the level of real wages across income groups. Table 3 details indices of real wages for the first, fifth and ninth earnings deciles for various OECD economies throughout the 1970s,1980s.and 1990s. These figures reveal clear increases in inequality in the Canada, the UK and US, while Sweden and France do not seem to observe such an increase in inequality. Another striking trend, is the absolute decline in real wages for the lowest decile in the US and Canada. While there are some studies which seem to account for this trend (e.g. Acemoglu (1999) and Caselli (1999)), Acemoglu (2000) argues that it is difficult for 'pure technology' stories of the rise in inequality to explain this fall in real wages.

Before we outline our model, we would also like to point out two distinguishing characteristics of skilled and unskilled labour markets. Firstly, as detailed in Table 4, retention rates[4] for unskilled workers are significantly lower than those for skilled workers. Additionally, it has generally been the case that, with the exception of Japan, the retention rates of unskilled workers have been falling faster than the retention rates of skilled workers. In other words, unskilled workers are facing greater job insecurity than skilled workers. This could reflect a fall in the relative demand for unskilled workers which leads to increased job reallocation among unskilled, as apposed to skilled workers - see Davis *et. al.* (1996)). Regardless of its cause, this will have implications for the relative impact of technical progress on the effort incentives of skilled and unskilled workers. Table 5 shows another key stylized fact that unemployment rates amongst unskilled workers are significantly higher across all countries than the unemployment rates for

[3] See Acemoglu (2000) for more references.

[4] Table 4 gives five year retention rates for different levels of educational attainment i.e. it shows the proportion of workers of a given level of education that remain with their current employer five years from now.

skilled workers. This has the implication that if a skilled worker faces a spell of unemployment following redundancy due to technical progress, she faces less competition for new vacancies than an unskilled worker in the same situation. This will also have implications for the changes in effort incentives of both types of worker in response to changes in technical progress.

3 The Model

3.1 Workers' Effort Incentives

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 $L = E_L(t) + U_L(t)$. Initially, we assume that H and L are fixed and do not allow for their endogenous determination.[5] 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, and.they will consume all their labour income, $w_i(t)$, $i = H, L$, as they receive it. They decide on whether or not to exert work effort when employed. The instantaneous utility function when employed is $w_i(t) - \varepsilon_i T(t)$, $i = H, L$. Consumers suffer disutility $\varepsilon_i T(t)$ if they exert effort, while shirking workers do not suffer this disutility. $T(t)$ is an index of the level of technology.

As we will see below, 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. However, 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

[5] This assumption will be relaxed in section 5 where we allow for the endogenous determination of $H$and L.

the job-to-job reallocation of workers in the US is more than a half of worker turnover. Table 4 also details retention rates for a sample of OECD countries diasaggregated by educational attainment. The data suggests that retention rates for skilled workers are significantly higher for skilled workers than unskilled workers, so that we would expect, $\eta_H > \eta_L$.

Given these assumptions, the return to the worker from being employed and not shirking, denoted by $V_i^N(t)$, is defined by the following 'asset' equation

$$\rho V_i^N(t) = w_i(t) - \varepsilon_i T(t) + b_i(t)\left[V_i^U(t) - V_i^N(t)\right] + \dot{V}_i^N(t), \qquad i = H, L \tag{1}$$

where $V_i^U(t)$ is the return from being unemployed. This equation says that the interest rate ρ times asset value $V_i^N(t)$ equals flow benefits ("dividends") of being an employed non-shirker. The flow benefits consist of a real wage $w_i(t)$, a disutility loss through not shirking $\varepsilon_i T(t)$, and capital gains. The capital gains arise due to technical progress and as net flows in the labor market affect the future probabilities employment relative to unemployment. The rate of worker dislocation, $b_i(t)$, will be endogenized later with the introduction of technological progress which destroys jobs.

If workers are employed, they also have the option to shirk. The value of being an employed shirker, denoted by $V_i^S(t)$, follows a similar recursive equation

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

Here the worker still enjoys the real wage but without disutility of efforts. Capital gains arise from job separation due to technological innovation or after being found be a shirker at a rate of s_i. If a worker keeps her job, she will enjoy capital gains $\dot{V}_i^S(t)$.

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

$$\rho V_i^U(t) = zT(t) + a_i(t)\left[V_i^N(t) - V_i^U(t)\right] + \dot{V}_i^U(t), \qquad i = H, L. \tag{3}$$

$zT(t)$ 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 a technological innovation creates new jobs. The rate at which workers of type i, $i = H, L$, are selected from the pool of unemployed for employment is given by $a_i(t)$. This job-acquisition rate will be endogenized below once technological progress, which creates jobs, is introduced.

Since the effort level of a shirker is zero, firms ensure that workers do not shirk, which requires $V_i^N = V_i^S$. Using this and equating (1) and (2) gives

$$v_i^N - v_i^U = \frac{\varepsilon_i}{s_i} \tag{4}$$

where $v_i^U = V_i^U/T$ and $v_i^N = V_i^N/T$ are productivity-adjusted values of being unemployed and employed respectively. This in turn implies

$$\dot{v}_i^N = \dot{v}_i^U, \qquad i = H, L. \tag{5}$$

3.2 Technological Progress

To focus on the impact of technological progress on wage inequality, we assume exogenous technological progress in the form of expanding variety. By definition, exogenous technological progress means that technology advances independently of economic factors, and the structure of the product market is irrelevant. Therefore, we assume perfect competition in all markets other than the labour markets.

There is a continuum of firms whose measure is one. A representative firm is endowed with the following production technology of final output (a numeraire)[6]

$$y = \int_0^n A_H x_H(j)^\alpha \, dj + \int_0^n A_L x_L(j)^\alpha \, dj, \qquad 1 > \alpha > 0, \quad A_i > 0, \; i = H, L \tag{6}$$

where x_i, $i = H, L$, are intermediate goods. x_H is produced with skilled workers only, and x_L with unskilled workers only on one-to-one basis. Technological progress is captured by an

[6] We drop the time argument unless ambiguity may arise.

increase in n (expanding variety) according to[7]

$$g = \frac{\dot{n}}{n} \tag{7}$$

Firms maximize profits by equating the marginal product of labour to real wage, giving the labor demand functions:

$$\omega_i = \frac{\alpha A_i}{(nx_i)^{1-\alpha}} \tag{8}$$

$$= \frac{\alpha A_i}{E_i^{1-\alpha}}, \qquad i = H, L \tag{9}$$

where $\omega_i = w_i/n^{1-\alpha}$ is productivity-adjusted wages. We define our index of technical progress as $T = n^{1-\alpha}$. Note that these demand functions are independent each other due to the assumed form of the production function. We can easily relax this assumption, but we do not explore this dimension, as it has been extensively analysed in existing studies.

In this paper, we are primarily interested in the effect of a higher g on wage inequality over the last 30 years. However, a brief discussion of how we can reconcile a higher g with the measured productivity slowdown since the early 1970s, followed by the surge of productivity in the 1990s, seems in order. There are different views on this issue. Starting from a practical approach, measurement problems are highlighted by Howitt (1998). Greenwood and Yorukoglu (1997) and Hornstein and Krusell (1996) argue that firms and workers initially have to use their time to learn how to use new technologies. Galor and Maov (2000) argue that a rapid technological progress deteriorates the productivity of low-skill workers. Acemoglu (1998) emphasizes the changing composition of skill-complementary and labor-complementary technological progress. All these arguments imply a temporary slowdown of productivity after an acceleration of technological progress. For our model, the approach of Galor and Maov (2000) can be introduced by simply assuming that $A_L(g)$ is a function of g and $A_L' < 0$. However, we do not explicitly consider this issue further, given the space constraint.

[7] The steady-state growth rate of y is given by $g_y = (1-\alpha) g_n$.

3.3 Labour Reallocation

A salient feature of technological progress is that new jobs are created as old jobs are destroyed. To explain how these features work in our model, consider the labor demand functions (8). x_i, $i = H, L$ is the number of workers used to produce a given variety, and it depends on the number of varieties of intermediate goods and the real wage. Log-differentiating the expression gives $-\dot{x}_i = x_i\left(g + \frac{1}{1-\alpha}\frac{\dot{\omega}_i}{\omega_i}\right)$. The left-hand side is the number of jobs lost in a given variety in time interval dt. 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 wage and 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 workers becoming unemployed in a given variety. However, recall an assumption we made earlier that a fraction η_i of workers who are separated from firms can find new jobs elsewhere. Therefore, the number of workers joining the unemployment pool from a given variety is $-(1-\eta_i)\dot{x}_i$. Therefore, the probability of a given worker becoming unemployed is given by

$$-(1-\eta_i)\frac{\dot{x}_i}{x_i} = (1-\eta_i)\left(g + \frac{1}{1-\alpha}\frac{\dot{\omega}_i}{\omega_i}\right) \quad (10)$$

$$= (1-\eta_i)\left(g - \frac{\dot{E}_i}{E_i}\right) \equiv b_i \quad (11)$$

where (11) is obtained by using $\frac{\dot{\omega}_i}{\omega_i} = -(1-\alpha)\frac{\dot{E}_i}{E_i}$ from the labor market condition (9). When employment E_i is constant, we have $b_i = (1-\eta_i)g$, $i = H, L$.

Next let us consider the flow of workers into and out of the unemployment pool. The number of workers becoming unemployed in a given variety during time interval dt is give by $x_i b_i$. Therefore, $nb_i x_i$ is the total number of workers being unemployed in an economy as a whole. As regards unemployed workers who find jobs, their number is given by $a_i U_i$. Therefore, changes in employment during time interval dt are $\dot{E}_i = a_i U_i - n x_i b_i$, which gives, upon rearrangement,

$$a_i = \frac{\eta_i \dot{E}_i + (1-\eta_i)\, g E_i}{U_i}. \tag{12}$$

3.4 Five Incentive Effects of Technological Progress

The main objective of this section is to identify five effects of technological progress on workers' effort incentives and their implications for wage inequality. Using $V_i^N = V_i^S$, $i = H, L$, equations (1) and (2) are solved for productivity adjusted wages $\omega_i = w_i / n^{1-\alpha}$, giving the individual's non-shirking condition (NSC):

$$\omega_i = [\rho - (1-\alpha) \underset{\text{(i)}}{g}] \left(v_i^U + \frac{\varepsilon_i}{s_i} \right) + \frac{\underset{\text{(ii)}}{g} - \eta_i \underset{\text{(iii)}}{g} + s_i - (1-\eta_i) \frac{\dot{E}_i}{E_i}}{s_i} \varepsilon_i - \dot{v}_i^N \tag{13}$$

Taking v_i^U as given and ignoring terms involving time derivatives, there are three channels through which the innovation arrival rate, g, affects ω_i. First, consider the term indicated by (i). This channel enters because technological progress results in increased returns to employment, which workers are more reluctant to give up by being found to be shirking. It therefore tends to strengthen the disciplinary effect of unemployment. We call this effect the *employment capitalization* effect of productivity growth. This is analogous to what Aghion and Howitt (1994) call the capitalization effect of growth on labour demand, which makes it profitable for firms to hire more workers.

The second effect is indicated by (ii). This is what we call the *job destruction effect* of productivity growth on workers effort incentives. The intuition is as follows. b_i is the rate of a worker being unemployed, and its inverse $1/b_i$ is the average duration of employment for workers. Further, equation (11) shows that b_i is increasing in g. That is, as g increases, the employment duration falls, weakening the disciplinary effect of unemployment. Hence firms are required to raise ω_i.

The third effect, indicated by (iii) in (13), comes from the fact that an employed worker may find a new job elsewhere immediately after being separated from the firm. This fact tends to lengthen the duration of employment and makes it more costly to be found shirking. Moreover, this effect becomes more important to workers as innovation occurs more frequently, due to a higher g. This strengthens the disciplinary effect of unemployment, allowing firms to lower ω_i. We call it the *job retention effect* of productivity growth. There are other effects which are realized through v_i^U. (13) shows that any effects which raise (or lower) v_i^U tend to increase (or decrease) ω_i. We turn to those effects now.

Substituting (13) into (3) and using (4), we obtain

$$v_i^U = \frac{z + \dfrac{\varepsilon_i}{s_i} \cdot \dfrac{\eta_i \dot{E}_i + (1-\eta_i) \overset{\text{(v)}}{\overset{\downarrow}{g}} E_i}{U_i} + \dot{v}_i^U}{\rho - (1-\alpha) \underset{\text{(iv)}}{\underset{\uparrow}{g}}}. \tag{14}$$

In (14), we can identify the fourth effect of g on ω_i, indicated by (iv). A higher g reduces the 'effective' discount rate that consumers capitalize future benefits as unemployed. That is, faster technological progress makes unemployment a more attractive option. We call this the *unemployment capitalization effect* of productivity growth. This effect tends to raise v_i^U, hence ω_i. Note that the unemployment capitalization effect moves in the opposite direction of the employment capitalization effect identified above. Since the steady-state flow benefits to unemployment are necessarily less than the flow benefits from employment,[8]the unemployment capitalization effect will be less than the employment capitalization effect.

The fifth effect is indicated by (v) in (14). It operates through the job-acquisition rate a_i for unemployed, which is increasing in g. Its inverse $1/a_i$ is the average duration of unemployment. As g rises, this duration falls and, as a result, the disciplinary effect of unemployment weakens.

[8] If 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.

This is termed the *job creation effect* of technological progress. Due to this effect, v_i^U rises in (14), and therefore firms have to raise ω_i. Note that as *more* jobs are created, real wages rise. This prediction sharply contrasts studies of technological unemployment arising from the labour demand side, as they show that more jobs reduce unemployment with a lower wage (see for example Aghion and Howitt (1994))[9]

3.5 Equilibrium Dynamics

Our assumption that the rate of detection of shirkers is less than infinite means that firms need to use a combination of higher wages and unemployment to provide workers with sufficient incentives not to shirk. Using (5), equations (14) and (13) can be rearranged into

$$\dot{E}_i = E_i \frac{(\omega_i - z)\dfrac{s_i}{\varepsilon_i} + \left[(1-\alpha) - (1-\eta_i)\dfrac{i}{i-E_i}\right] g - \rho - s_i}{\dfrac{\eta_i i}{i-E_i} + 1}. \quad i = H, L \tag{15}$$

This is the aggregate *NSC* for workers of type i. In steady state, where $\dot{E}_i = 0$, this condition reduces to,

$$\omega_i = z + \varepsilon_i \frac{\rho - (1-\alpha) \overset{\overbrace{(\text{i}),(\text{iv})}}{\overset{\downarrow}{g}} + \overset{\overbrace{(\text{ii}),(\text{iii}),(\text{v})}}{\overset{\downarrow}{g}} \times \dfrac{(1-\eta_i)}{1-E_i/i} + s_i}{s_i}. \quad i = H, L \tag{16}$$

Figure 1 depicts (16) and the labor demand function (9) with ω_i^* denoting the equilibrium, productivity adjusted wages of workers of type i.

Suppose that initially employment is given by E_i^0. Profit maximising behaviour on the part of firms implies that the economy must be on the labor demand curve at every point in time, giving ω_i^0. Then, the economy moves along the labor demand function towards a long-run equilibrium. This analysis implicitly assumes that the adjustment of employment is not instantaneous. There

[9] This difference arises since those studies focus exclusively on firms' hiring/firing decisions, and by doing so, neglect the effort incentive effects of job creation.

are two possible reasons for gradual employment adjustment as a plausible case, as suggested by Kimball (1989). First, a jump in aggregate employment requires synchronization across firms in both the timing and magnitude of hiring and firing. This seems difficult in practice. Second, adjustment costs would make a discontinuous change in employment extremely costly. In fact, Kimball (1989) shows the existence of sunspot equilibria in the Shapiro-Stiglitz model, and Georges (1994) proves that an equilibrium of gradual employment adjustment is obtained as a unique equilibrium as the adjustment costs go to zero. This result still applies to our model.

Note that in the NSC (16), the unemployment and employment capitalization effects are combined as a single net effect, (i),(iv), as are the (ii) the *job destruction* effect; (iii) the *job retention* effect, and (v) the *job creation* effect. Note that these three effects (ii), (iii) and (v) are caused via the labour reallocation process. An immediate implication of this result is that technological progress which does not result in worker reallocation always reduce ω_i due to the net employment capitalization effect.[10]This reveals that there are two basic competing tendencies determining the impact of growth on effort incentives. Firstly, higher g reduces the effective discount rate, such that the growth in real wages that emerges from non-skill biased technical progress, cet. par., raises the value of employment relative to employment and reduces the incentives to shirk. The second, offsetting, tendency arises due to the worker reallocation induced by technical progress, thereby increasing job turnover, so that workers have less incentive to avoid shirking since they could easily lose their jobs through technical progress anyway. The size of this effect is reduced when the rate of retentions, η_i, is high and when there is a low rate of employment.

[10] All effects due to labour reallocation disappear for $\eta_H = 1$. In (16), this means that E_H no longer affects ω_H. However, this is not true in general. For example, if we assume an exogenous rate of job separation unrelated to technological progress, ω_H will be a function of E_H, and one can easily verify that a higher g reduces ω_H due to the employment capitalization effect.

4 Explaining Wage Inequality

4.1 A Benchmark Case

Initially, we assume that firms can monitor the effort levels of unskilled workers perfectly. Therefore, the instantaneous probability of being found shirking is infinite, $s_L \to \infty$ and there is no need to use efficiency wages and/or unemployment as a worker disciplining device Then, substituting (13) into (17) and using (5) gives the unskilled non-shirking condition[11]

$$\omega_L = z + \varepsilon_L. \tag{17}$$

In other words, unskilled workers operate in a competitive market where their wages are equal to their reservation wages which must compensate them for the disutility of effort, $\varepsilon_L$and the level of unemployment benefit, z. Since workers in this market will be indifferent between employment and unemployment, turnover in the unskilled labour market is not an issue for them, and unskilled wages will be independent of g and A_L. We take this as a benchmark case with which we can compare skilled wages, and we discuss later what happens if this assumption is relaxed.

Our next objective is to re-examine the acceleration hypothesis outlined in section 2, from the perspective of the supply-side of the labor market. For this purpose, we distinguish between (a) increased skill bias without acceleration of the overall (skill-neutral) rate of technological progress, and (b) acceleration of the overall rate of technological progress. Note that accelerated skill-biased technological progress can arise due to effect (a) alone or in combination with effects (b). To capture these effects, let us assume $A_i(g)$ is a function of g such that $A'_H(g) \geq 0$ and $A'_L(g) \leq 0$. Then, we make the following definitions:

Case 1 *(effect (a)) Increased skill-bias without acceleration of the overall rate of technological*

[11] As long as $z > \alpha A_L / L^{1-\alpha}$, some unskilled workers are unemployed.

progress for $dA_H > 0$, $dA_L < 0$, *and* $dg = 0$.

Case 2 *(effect (b)) No skill-bias with acceleration of the overall rate of technological progress for* $dg > 0$.

Case 3 *(Combination of effects (a) and (b)) Increased skill-bias with acceleration of the overall rate of technological progress for* $dg > 0$, $A'_H(g) > 0$, *and* $A'_L(g) < 0$.

4.2 Accelerated Skill-neutral Technological Progress

First we examine Case (2), as it will facilitate analysis in the following sections. Moreover, the case of accelerated skill-neutral technological progress may also be of independent interest, since not all technological progress that has taken place in the recent past is skill-biased. Katz and Murphy (1992, p.62) show that skill-neutral technological progress is the main driving force in the acceleration of the overall technological progress in the 1970s relative to the previous decade, while skill-biased technological progress took over that role in the 1980s. Moreover, empirical studies do not make clear whether skill-biased technological progress arose from Case (1) or Case(2) (e.g. Autor, *et al.* (1998)).

Differentiating the long-run *NSC* (16) yields

$$\frac{\partial \omega_H}{\partial g}\begin{cases} \geq 0 & \text{for } E_H \geq \widehat{E}_H \\ < 0 & \text{for } E_H < \widehat{E}_H \end{cases} \quad \text{where } \widehat{E}_H = \frac{\eta_H - \alpha}{1-\alpha} H < H. \tag{18}$$

This shows that there exists a threshold level of employment $\widehat{E}_H$ above which ω_H rises and below which ω_H falls. This is demonstrated in Figure 2 where the solid *NSC* ($\dot{E}_H = 0$) pivots to the dotted curve around a point corresponding to $\widehat{E}_H$. The intuition is simple. We showed that a rapid technological progress creates five types of effort incentive effects, (i) the employment capitalization effect, (ii) the job destruction effect; (iii) the job retention effect, (iv) the unemployment capitalization effect and (v) the job creation effect. Effects (i) and (iii), which tend to reduce ω_H by strengthening the disciplinary effect of unemployment, more than offset the other effects in the region where $E_H < \widehat{E}_H$, and the reverse holds where $E_H > \widehat{E}_H$.[12]Notice that the critical rate of employment, $\widehat{E}_H$ depends upon the extent to which workers retain their jobs in the face of the technical progress - skilled workers which are observed to enjoy higher retention ratios and employment rates are therefore more likely to be operating in the region where $E_H > \widehat{E}_H$.

Having established this, we examine how accelerated skill-neutral technological progress affects wage inequality. Figure 2 shows the case where the equilibrium rate of skilled employment and the retention rate are relatively high. The labor demand curve D intersects the NSC at a point B_1 which is located to the right of the threshold $\widehat{E}_H$. As skill-neutral technological progress accelerates, the economy moves to a new long-run equilibrium B_2. It is clear that skilled wages rise in this dynamic adjustment. It results in increasing wage inequality, given that unskilled wages are constant (see (17)). Moreover, this case predicts that the unemployment rate will increase as wage inequality gets worse. In fact, this is what happened in the US in the past decades. The unemployment rate of college graduate workers stood at 1.1% in 1970, and it increased threefold to 3.2% on average between 1992 and 1994.[13]

Proposition 4 *Accelerated skill-neutral technological progress can increase wage inequality.*

4.3 Skill Bias: Overshooting Skilled Wages

Now suppose we consider an increase in skill-biased technical progress siuch that A_H increases (and A_L falls). Then the demand for skilled labour will shift right as depicted in Figure 3. The long-run equilibrium moves from B_1 to B_3. However, in the short-run the economy moves

[12]If technological progress does not cause labor reallocation, i.e. $\eta_H = 1$, then effects (ii), (iii) and (v) disappear, and we have $\partial\omega_H/\partial g < 0$.

[13]In fact, the unemployment rates of all education groups increased during the same period (see Acemoglu (1999)).

to B_2 with ω_H overshooting its equilibrium value of ω_H^*. Profit maximising behaviour on the part of firms implies that they will remain on their labor demand curves at all points in time. However, in the short-run they can lie off the steady-state no-shirking condition. The reason for this is that if firms attempted to hire all the additional workers they want immediately, then the increased hire rate would have a detrimental effect on the effort incentives of their employees. Therefore, employment does not jump to the new equilibrium, instead the hire rate rises above its steady-state value and wages have to be correspondingly higher to ensure that workers maintain their effort levels. For as long as the hiring rate is above its steady-state value, real wages must also lie above their steady-state value.

We now to turn to analyze the combination of an increase in the rate of technical progress which is biased towards skilled labour. This case is analyzed in Figure 4. Here the initial jump in skilled wages is identical to the case of skill biased technical progress which is not combined with an increase in the overall rate of technical progress. However, the extent to which this can be considered an 'overshooting' of inequality is affected. If we are again in the region where $E_H > \widehat{E}_H$ then the rotation in the NSC due to the higher rate of technical progress will imply that the initial jump in wages will not decline to the same extent after firms have increased their rates of employment.

Proposition 5 *Skilled wages overshoot the long-run equilibrium, as skill-biased technological progress accelerates.*

4.4 Technical Progress and the Unskilled Labor Market

Until now we have assumed that firms could perfectly monitor the effort levels of their employees in the unskilled sector. As a result the wages paid in the unskilled sector were equal to workers' reservation wages, $\omega_L = z + \varepsilon_L$. This then served as a benchmark against which we could compare the level of wages in the skilled sector. We now relax the assumption that there is perfect monitoring in the unskilled sector by assuming, $0 < s_L < \infty$. Firms in this sector now need to use unemployment and wages as a disciplining device to elicit effort from their employees. As a result there is now a NSC in this sector similar to (15) and (16) but where the subscript H is replaced with L. The only difference between the analysis we conducted above and the analysis applicable to the unskilled sector is that skill biased technical change is likely to imply leftward shifts in demand, and the empirically observed high unemployment rates and low retention rates for unskilled workers make it likely that $E_L - \widehat{E}_L < E_H - \widehat{E}_H$.[14]

Figure 5 considers the case of an acceleration in skill-neutral technical progress. The figure is drawn such that the original equilibrium rate of employment lies in the region to the left of $\widehat{E}_L$. The acceleration in technical progress then rotates the equilibrium no-shirking condition anti-clockwise around a point determined by the threshold rate of employment, $\widehat{E}_L$. The economy moves from point B_1 to B_2 with a lower level of productivity adjusted wages, but a higher rate of employment. If we compare figure 5 with figure 2 we see that the same acceleration in technical progress increased wages in the skilled labor market rather than reduced them. It should be noted that even if both labor markets had employment rates on the same side as the threshold rate (i.e. $E_i < \widehat{E}_i$, or $E_i > \widehat{E}_i$, for $i = H, L$) then skill neutral technical progress would still result in a relative increase in inequality provided $E_L - \widehat{E}_L < E_H - \widehat{E}_H$.

We now turn to the case of a relative shift in demand towards skilled workers without any increase in the overall rate of technical progress. This is analyzed in Figure 6 where the leftward shift in demand moves the equilibrium from B_1 to B_3. However, in the short-run there is an undershooting of unskilled wages - the reduction in hiring rates mean that firms can suppress

[14] For pedagogical purposes we draw all our diagrams under the assumption that $E_L < \widehat{E}_L$ and $E_H > \widehat{E}_H$. However, all that our qualitative results require is that $E_L - \widehat{E}_L < E_H - \widehat{E}_H$ which seems likely given the relative rates of unemployment and retention rates in the skilled and unskilled labor markets.

unskilled wages without fear of a reduction in worker effort as workers realize that it is will increasingly difficult to find work if they are fired when unemployment is rising in the unskilled labour market. Eventually, the unskilled market will reach its new steady-state with a lower equilibrium wage and higher unemployment at point B_3. The undershooting of productivity adjusted real wages will also imply an initial decline in unadjusted real wages. Although our model cannot strictly account for a sustained fall in real wages, such as that observed in the US, it could be extended to include a number of industries employing unskilled labour which are hit by an acceleration in skill biased technical change one by one. As the wages of unskilled workers fall in each industry this could sustain the gradual decline in real wages observed in the US data and the gradual increase in unskilled unemployment.

It also seems plausible to assume that the demand curves shifted in several steps due to a gradual increase in the bias towards skills. In this case, the short-run overshooting of wage inequality would also be sustained for an extended period. This result implies that wage inequality can be highly volative due to the transitory nature of wage inequality. In fact, a common finding across studies and data sets is that an increase the transitory component of earnings variation is as important as a rise in the permanent component in explaining a sharp rise in cross-sectional earning inequality in the US. For example, Gottschalk and Moffitt (1994) showed that the permanent and transitory components of log male earnings both increased by about 40 % from 1970s to the 1980s. Moffitt and Gottschalk (1995) also showed that an approximately equal increase in the permanent and transitory variances contributed to a rise in cross-sectional residual inequality for males in the 1980s. These studies imply that earning inequality is highly unstable. Our model offers a possible explanation for this finding.

If we now combine the acceleration in the overall rate of technical progress with an acceleration in skills bias, then we obtain the results shown in Figure 7. Suppose, that the late 60s describes a period when the retention rates for unskilled workers were still fairly high and the unemployment rates where relatively low. In this case we may be in the region where $E_L > \widehat{E}_L$, with the equilibrium determined by the intersection of the demand and NSC curves D_1 and $\dot{E}_L^1 = 0$. A shift in relative demand (from $D_1$to D_2) towards skills combined with an acceleration in the overall rate of technical progress is likely to lead to an immediate drop in real wages, but with a partially offsetting rise occurring after the hiring rate returns to its steady-state value due to the rotation of the no shirking condition (from $\dot{E}_L^1 = 0$ to $\dot{E}_L^2 = 0$). If the demand for unskilled workers continues to shift leftward due to skill-biased technical progress (from D_2 to D_3) then there will be a continued fall in real wages with only a limited subsequent recovery due to the rotation of the NSC (from $\dot{E}_L^2 = 0$ to $\dot{E}_L^3 = 0$). Therefore, the reduction in unskilled workers' retention rates and the increases in their rates of unemployment observed since the 1970s suggest that any skill biased technical progress is likely to reduce unskilled wages in the short-run with only a modest recovery in the medium run once the downsizing of the sector is complete.

Proposition 6 *Unskilled wages undershoot the long-run equilibrium, as skill-biased technological progress accelerates.*

We have established that there is overshooting of the increase (decrease) of skilled (unskilled) wages relative to the long-run equilibrium following accelerated skill-biased technological progress. This implies that wage inequality overshoots the long-run degree of inequality. This implies that the large increases in observed inequality increasing may be, at least partially, a temporary phenomenon. The good news is that empirical studies show that skill-biased technological progress may have decelerated in the 1990s (Autor, *et. al.* (1998))

Proposition 7 *Wage inequality overshoots the long-run equilibrium, as skill-biased technologi-*

cal progress accelerates.

4.5 Policy Analysis

Our model also allows for some simple policy analysis. In figure 8, increasing unemployment benefits (a higher z) directly raises the real wage required to prevent shirking in the skilled labour market. It also increases reservation wages in the unskilled market when there is perfect monitoring. By raising both skilled and unskilled wages by the same amount it does nothing to reduce the absolute difference in skilled and unskilled wages, but it does reduce their ratio. Similarly higher income taxation will also shift the NSC upwards by the amount of the tax.[15] While this policy analysis is standard, what it does suggest is that by raising the equilibrium rate of unemployment in each market, cet. par., we are less likely to find ourselves in the region where $E_i > \widehat{E}_i$. To the extent that unemployment benefits are more generous and income taxation is more progressive in Europe than the US and equilibrium unemployment rates are therefore higher, then equilibrium employment, E_H, is more likely to lie to the right of the threshold, $\widehat{E}_H$, in the US than Europe. This means that any acceleration in technical progress, independently of any skills bias, is less likely to raise inequality in Europe than in the United States.

4.6 Wealth Effect

In this section we introduce a simple extension to our model which creates an interdependence between demand and supply in our labour markets. Specifically, we introduce an extension suggested by Kimball(1994) by assuming a wealth effect whereby higher wages increase the disutility of worker effort such that,

$$\varepsilon_H(\omega_i), \qquad \varepsilon_i' > 0 \;\; i = H, L \tag{19}$$

[15] When labour income taxation is introduced, ω_i $(i = H, L)$, in the value functions (1) and (2) is multiplied by $1 - \tau$, where τ is the tax rate. Therefore, the right hand side of the aggregate NSC (16) is divided by $1 - \tau$ and the NSC in the figure shifts upwards.

This specification captures the the kind of wealth effects examined by Phelps (1994). In Figure 9, in the absence of the wealth effect, the equilibrium would move from B_1 to B_2, following a shift in demand. However, the higher skilled wages generated by skill biased technical progress raise the disutility of worker effort. This causes the NSC to shift upwards, such that the increase in skilled wages is heightened. Conversely, in the unskilled labour market, the fall in real wages due to the leftward shift in the demand curve is exacerbated by the negative wealth effect this generates.

Proposition 8 *The introduction of the wealth effect amplifies wage inequality.*

5 Long-Run Wage Inequality

5.1 Endogenous Determination of H and L

So far we assumed that H and L are given. This is a plausible assumption for the short or medium run. However, it is plausible to assume that in the long run workers decide whether or not to attain the education necessary to become skilled or unskilled on the basis of economic incentives. Once this aspect is introduced, further interesting implications will emerge. For this purpose, this section allows for the endogenous determination of the proportion of skilled and unskilled workers in the economy.

First we assume that workers have a finite working life and, for simplicity, we model this by assuming workers face a constant exogenous probability of death, k. The total number of workers at a given time is normalized to one. This implies that a new generation of workers of size k is entering the labour market at each point in time. If we were to retain our assumption that H and L were given then it should be obvious that a no-shirking constraint would be of the same basic form as (16), except that the discount rate is equal to individuals' rate of time preference ρ, plus a 'mark-up' reflecting the probability of death, k, i.e.

$$\omega_H = z + \varepsilon_H \frac{\rho + k - (1-\alpha) g + g \frac{(1-\eta_H)}{1 - E_H/H} + s_H}{s_H}. \tag{20}$$

This can be thought of as the medium-run no shirking condition, since the size of the skilled labor market H is treated as constant. However, in the long-run H is endogenously determined based on economic incentives.

To model this we assume that new born workers entering the labour market must make, at 'birth' an irreversible life-time career decision on whether or not to become a skilled worker. Workers become skilled only through education (or training), and are otherwise unskilled.[16]We assume that education involves incurring a worker specific fixed cost $C(j)T(t)$ which will enable the j-th member of the new cohort of workers to be permanently labelled as 'skilled'. We also assume that workers are heterogeneous in their ability to attain the skills necessary to compete in the skilled labor market, and we order the new workers over the interval $j \in (0, k)$ such that $C(j)$ is increasing in j. We further assume that this distribution of the cost across workers is the same for each new cohort. The assumption of heterogeneous education costs captures "diminishing returns to education" from the viewpoint of society in the following sense. Intuitively, more able individuals with lower education costs undertake education first, and then less able workers with higher training costs follow suite. Then, as more and more new workers choose to become skilled, the marginal cost of educating them will rise. On the other hand, if education costs are identical across all new generations, then we have constant returns to education. As we will show below, the extent to which the returns to education change as the number of trainees increases, determines the impact of skill-biased technical progress on wage inequality in the long run.

[16]For simplicity we do not allow workers who have entered the unskilled labour market to retrain as skilled workers. Instead we focus upon the level of schooling attained before entering the labour market.

Given the assumptions made above, the change in the proportion of skilled workers in the economy is given by $\dot{H}(t) = e(t)k - kH(t)$ where $e(t)$ represents the proportion of new born workers who become skilled. Offsetting these inflows are those who die at the rate k. Similarly the change in the proportion of unskilled workers is given by $\dot{L}(t) = (1 - e(t))k - kL(t)$. Note that we have $e = H$ and $1 - e = L$ in steady state.

Next we describe what determines the proportion of new workers that opt to incur the cost of education. We assume that all new workers enter the pool of (skilled or unskilled) unemployment, i.e. workers start their career as unemployed. Therefore, in order to decide whether or not to become educated, new born workers will compare the asset value of being an unskilled worker, v_L^U, with the asset value of entering the skilled labor market, v_H^U. More specifically, e is determined by $v_H^U - v_L^U = C(e)$ where the left hand side represensts the rents accruing to a threshold worker who is indifferent between being skilled and unskilled. Appendix A shows that this arbitrage condition is given by

$$\frac{g(1-\eta_H)\varepsilon_H}{s_H[\rho + k - g(1-\alpha)](H/E_H - 1)} = C(H) \tag{21}$$

in steady state when $e = H$. Note that we have $C'(H) > 0$ due to diminishing returns to education. The left-hand side of equation (21) is the net benefit to the threshold new born worker, and it is decreasing in H. Intuitively, as more new workers choose to be educated, skilled wages fall for a given E_H, hence the net benefit of being skilled drops. Since the education cost $C(H)$ is increasing in H, the long-run number of skilled workers is uniquely determined for a given E_H.

The arbitrage condition (21) links H and E_H such that $H = H(E_H)$ and $H'(.) > 0$. This relationship is substituted into the medium-run NSC (20) to to obtain,

$$\omega_H = z + \varepsilon_H \frac{\rho + k - (1-\alpha)\, g + g \dfrac{(1-\eta_H)}{1 - E_H/H\,(E_H)} + s_H}{s_H} \tag{22}$$

This can be thought of as the long-run no shirking condition which operates once workers have obtained their desired level of education and the size of H has been endogenously determined. Appendix A shows that $E_H/H\,(E_H)$ is monotonically increasing in E_H. Therefore, the equilibrium level of productivity adjusted wages is increasing in H due to diminishing returns to education. Intuitively, a higher steady-state value of H requires that more new workers should become educated. This means that less able individuals with higher education costs decide to become skilled. However, these less able workers require a higher return from being skilled to compensate for the high cost of training. This leads to a higher skilled wage.

Notice that in the long-run, if all workers were homogenous, such that C was constant for all workers, then the level of skilled wages would be independent of both the size of the skilled market, and the rate of unemployment in the skilled market. This is shown in Appendix A.

We now examine the effect of increasing skill bias, which increases the demand for skilled workers. This situtation is drawn in Figure 11. Assume that initially the economy is in long-run equilibrium B_1 with the level of wages ω_H^1, the level of employment E_H^1, and the number of skilled workers H_1. This equilibrium is consistent with the medium-run NSC (20), the demand curve, and the education arbitrage condition (21). An increased skill bias then shifts the demand curve rightward. The initial reaction, before employment and the take-up of skill enhancing education can respond, is for real wages to jump to ω_H^2. As we established earlier, this represents the overshooting of skilled wages.

During the time period in which the skilled workforce H does not change, firms would slowly hire unemployed skilled workers until the economy reached an equilibrium at point B_3. Once the economy had reached that point, there would no longer be any increase in the hire rate and real wages could settle at their medium run equilibrium. However, in the long run, new entrants to the labor market see the higher rents that skilled workers are now earning and they have greater incentives to incur the costs of retraining. Following their education they will enter the skilled labor market, thereby shifting the medium run NSC to the right, as shown in Figure 11. This process will continue until the medium run NSC intersects the demand curve at a point B_4 which lies on the long-run NSC. Note that wage inequality caused by skill-biased technological progress does not disappear even in the long run. The key mechanism behind this result is diminishing returns to education. As long as some people are better at attaining skills than others, wage inequality will persist.

Proposition 9 *(The non-neutrality result) Skill-biased technological progress increases wage inequality in the long run when the cost of education cost heterogeneous across individuals.*

On the other hand, if workers are homogeneous in education costs, the effect of an increased skill bias on wage inequality is zero in the long run. This should be clear from Figure 11. The medium-run NSC continues to shift rightward until the economy reaches a point B_5, which lies on the horizontal long-run NSC at ω_H^1. This gives rise to the following proposition,

Proposition 10 *(The neutrality result) Skill biased technological progress has no impact on wage inequality in the long run when the cost of education is identical across individuals.*

This analysis suggests that the recent increases in inequality may be, to some extent, a temporary phenomenon. Initially, the labor flows arising from the adjustment to a new rate of employment following skill-biased technical progress will tend to require higher inequality to prevent shirking. Once these adjustments have passed there will still be an increase in inequality, although not to the same extent as the initial impact. In the longer-term, this increase in inequality is likely to encourage new workers to obtain the education necessary to compete in the skilled labor market. This endogenous increase in the supply of skilled workers is likely to further offset the initial increase in inequality. However, to the extent that some individuals find it more costly than others to obtain skills through education then this will limit the ability of this supply effect to offset the rise in inequality.

5.2 Hysteresis

In this section we introduce a simple externality to the process of education. Specifically, we assume that when the econony contains a large proportion of skilled workers, the educational system is likely to be geared towards providing the education required to participate in the skilled labor market. This assumption works against the rising marginal cost of training due to heterogenous workers since, as more workers become educated, the education system is better able to educate the next trainee, *cet. par.*. Somewhat surprisingly, therefore, this consideration can amplify the non-neutrality result due to the existence of multiple equilibria. In particular,we show that long-run wage inequality is determined by the intitial level of employment (and inequality), i.e. the economy is characterised by hysteresis.

We maintain the above framework and assume that workers face identical training costs for simplicity. We also continue to assume perfect monitoring in the unskilled labor market. In this case, as established above, the long-run NSC for skilled workers is horizontal, as shown in Figure 11. A simple, but important deviation from this setting is due to an additional assumption that training costs are a decreasing function of the level of skilled employment, i.e. $C(E_H)$ where $C'(.) < 0$, $C(0) < \infty$, and $C(\infty) > 0$. This captures in a simple way a positive externality of the skills of existing workers on those who are contemplaiting their life-time career. $T(t)\,C(E_H)$ is a education cost that must be incurred before new-born workers acquire skills.

Under this assumption, the NSC is now given by (see Appendix B for derivation)

$$\dot{E}_H = \frac{\frac{\varepsilon_H}{s_H}\left[s_H + (1-\eta_H)\, g\right] + z + \left[\rho + k - (1-\alpha)\, g\right] c\,(E_H) - \omega_H}{\frac{(1-\eta_H)\,\varepsilon_H}{s_H E_H} + C'\,(E_H)}. \tag{23}$$

The long-run NSC (when $\dot{E}_H = 0$) is now decreasing in E_H, as depicted in Figure 12. This is due to the externatility introduced. Given the downward-sloping labor demand curve, multiple equilibria are possible. Figure 12 shows the case of three long-run equilibria. An equilibrium B_1 is unstable, while B_2 and B_3 are stable. Note that B_3 (B_2) is a high (low) wage inequality equilibrium given the level of unskilled wages. Given that employment does not change instantaneously, the economy moves to either stable equilibrium. If the initial level of employment is lower than the threshold E_H^1, a high inequality equilibrium B_3 is eventually reached. Otherwise, a low inequality equilibrium B_2 will be attained. Thus, the long-run equilibrium depends on the initial level of employment, i.e. there is hysteresis in long-run wage inequality.

To reach a high inequality equilibrium from a relatively high employment, we should observe both rising wage inequality *and* an increasing rate of skilled unemployment.[17]The US unemployment rate of civilian labor force with college degrees stood at 1.3% in 1970, and rose to 2.9% in 1991.[18]A rise in unemployment rate is more pronouced for civilian males. Their unemployment rates are 1.1% and 3.2% in 1970 and 1991, respectively. These numbers suggest that long-run high wage inequality is a possibility.

Next let us discuss how the long-run equilibrium changes for Case (1) an increase in pure skill bias, and Case (2) accelerated skilled-neutral technological progress. For this purpose, we

[17]It is not immediately obvious from Figure 12 that a lower E_H means a higher skilled unemployment rate, as H is also endogenous. But This can be easily established from the arbitrage condition (21), which is

$$\frac{\varepsilon_H\,(1-\eta_H)\, g}{s_H\left[\rho + k - (1-\alpha)\, g\right](H/E_H - 1)} = c\,(E_H)$$

for this extended model.

[18]*Statistical Abstract of the United States*, 1996, Table 656, p.420 (http://www.census.gov/prod/www/statistical-abstract-us.html). A similar upward trend is also found in other developed economies (see Nickell and Bell (1995)).

assume that the initial employment is between two long-run equilibria B_2 and B_3, for it presents an interesting case. Figure 13 depicts Case (1). As the skilled labor demand shifts outward, a high wage inequality equilibrium B_2 is eliminated. Moreover, long-run wage inequality will also be smaller at B_4. In this sense, the long-run non-neutrality of an increased skill biase established in the preceeding section does not hold. As the economy converges to B_4 from left, we should be able to observe a falling unemployment and narrowing wage inequality.

On the other hand, the opposite result is obtained for Case (2). Figure 14 shows that the long-run NSC pivots at $\widehat{E}_H$ as g gets larger. This can be easily confirmed from (23).[19] An accelerated skill-neutral technological progress moves the high inequality equilibrium to B_4 from B_3. However, it eliminates the low inequality equilibrium B_2. If the initial equilibrium is at B_2, the non-neutrality result established above holds, and in the long-run inequality actually worsens as a result of endogenous training decisions. As the economy approaches the new long-run equilibrium B_4 from the right, unemployment rises gradually and wage inequality follows suite. The data shows a similar time path of unemployment, as mentioned earlier.

Proposition 11 *The externality of skilled workers on the education decisions of new born workers can exercerbate wage inequality in the long run.*

6 Conclusion

In this paper we developed the efficiency wage model of Shapiro and Stiglitz (1985) to allow for the fact that technical progress can result in worker-firm separations. We identified five effects of technical progress on the effort incentives facing workers. Firstly, the model contains a net *capitalization effect* - the higher rate of growth increases incomes and increases the returns to employment, *cet. par.*. However it also gives rise to some labour reallocation - the basic *job*

[19] To highlight an interesting case, the figure depicts the case where $\widehat{E}_H$ is located to the left of B^1.

destruction effect, whereby technical progress will reduce the expected duration of employment, reducing work incentives and increasing unemployment. However, workers avoid this cost if they are flexible enough to retain their jobs or immediately switch to a new job in the face of technological change. We call the change in the relative values of employment and unemployment due to the job security that comes from flexibility in the face of technical progress the *job retention effect*. The final effect we identify is the *job creation effect* of technological progress. In studies which focus on the demand side of the labour market, it is clear that when more jobs are created, the unemployment is lower. However, on the supply side, as more jobs are created, the average duration of unemployment of those fired because they were found to be shirking also drops and this weakens the disciplinary effect of unemployment.

There are basically two competing tendencies within these five effects of growth on unemployment. Through the job destruction and creation effects, raising growth increases turnover in the labour market, and therefore reduces the incentives to avoid shirking in order to retain one's job. However, if workers enjoy a measure of job security, then increasing growth can raise the returns to employment relative to unemployment, and workers will have less incentive to shirk in order to retain their jobs and enjoy the benefits of increased economic growth.

Given these opposing effects on the supply side of the labour market, technological progress can either reduce or raise wages. However, the critical level of unemployment, above which a faster rate of technological innovation decreases wages depends upon the degree of job security enjoyed by workers in that labour market. Since, most empirical studies suggest that unemployment is higher amongst unskilled workers relative to skilled workers and their degree of job security is lower, this means that technological progress, even when it is skill neutral, will increase wage inequality.

Additionally, since the impact of skill neutral technological progress on inequality depends on the equilibrium rate of unemployment in the labour market, this implies that variables which determine the equilibrium rate of unemployment should affect the strength of the impact of growth on inequality. This has important implications for policy. For example, we find that unemployment benefits increase unemployment, as in the original Shapiro-Stiglitz model, but the policy makes it less likely that technological progress increases inequality. The existence of labor market policies that raise the equilibrium rate of unemployment, may explain why there has been a less marked increase in inequality in Europe compared with the US.

When we consider the impact of an acceleration in skill-biased technical progress, we find that any shift in relative demand towards skilled workers is likely not only to increase the equilibrium level of inequality, but to lead to an overshooting of inequality in the short-run. This arises as the increased hire rates for skilled workers requires higher wages to prevent these workers from shirking, while the increased rates of redundancy for unskilled workers allows firms to reduce unskilled wages without compromising unskilled workers effort incentives. , requires increases in wages of skilled wooFurther extending the model to consider possible interactions between shifts in relative demand and incentive effects of unemployment suggests that Phelps (1994) type wealth effects will also exacerbate the increases in inequality arising

We then consider individuals' decisions to undertake the training required to participate in the skilled labor market. Following an increase in skill-biased technical progress, inequality rises and workers face greater incentives obtain the skills that would allow them to enter the skilled labor market. When the cost of obtaining this education is constant across workers then any increase in inequality due to skill-biased technical progress will eventually be eliminated through increases in the relative supply of skilled workers as they respond to these incentives. To the extent that workers face different costs/abilities in equipping themselves with skills, then this mechanism will be incomplete and technical progress that raises inequality in the short-run will also raise it in the long-run. We then extend this training decision further, by introducing a simple externaility whereby the number of skilled workers in the economy determines the costs of obtaining skills. The idea being, that if the workforce is already highly skilled, the education system is likely to be geared towards equipping workers with the skills they need to compete in the skilled labor market. This externality, can give rise to multiple equilibria in inequality in the long-run. We demonstrate that where the economy ends up depends upon the the initial level of employment (and inequality), such that the level of inequality in an economy has a hysteretic quality. The impact of accelerated technical progress on inequality can be ambiguous in this case, although examples of labor market behaviour which correspond to the stylized facts can be deduced.

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Appendix A

This appendix, first of all, derives equations (21) and (22) and, secondly, establishes that the long-run NSC is increasing in E_H for $C(j)$ where $C'(j)$. The productivity-adjusted values of being (1) an employed non-shirker, (2) an employed shirker, and (3) unemployed for skilled and unskilled workers are given by the following equations respectively:

$$[\rho + k - (1-\alpha) g] v_i^N = \omega_i - \varepsilon_i + b_i \left[v_i^U - v_i^N\right] + \dot{v}_i^N, \qquad i = H, L, \tag{24}$$

$$[\rho + k - (1-\alpha) g] v_i^S = \omega_i + (b_i + s_i) \left[v_i^U - v_i^S\right] + \dot{v}_i^S, \qquad i = H, L, \tag{25}$$

$$[\rho + k - (1-\alpha) g] v_i^U = z + a_i \left[v_i^N - v_i^U\right] + \dot{v}_i^U, \qquad i = H, L. \tag{26}$$

(24) and (25) gives

$$v_i^N - v_i^U = \frac{\varepsilon_i}{s_i}, \qquad i = H, L \tag{27}$$

which implies

$$\dot{v}_i^N = \dot{v}_i^U, \qquad i = H, L \tag{28}$$

Using (27), equations (24) and (26) can be rewritten as

$$[\rho + k - (1-\alpha) g] v_i^N = \omega_i - \varepsilon_i - b_i \frac{\varepsilon_i}{s_i} + \dot{v}_i^N, \qquad i = H, L, \tag{29}$$

$$[\rho + k - (1-\alpha) g] v_i^U = z + a_i \frac{\varepsilon_i}{s_i} + \dot{v}_i^U, \qquad i = H, L. \tag{30}$$

Now let $s_L \to \infty$. Then, (27) gives

$$v_L^N = v_L^U, \tag{31}$$

which, together with (26), implies

$$v_L^U = \frac{z + \dot{v}_L^U}{\rho + k - (1-\alpha) g}. \tag{32}$$

For the threshold new born worker who are indifferent between being skilled and unskilled,

$$v_H^U - v_L^U = C(e) \tag{33}$$

must hold. This implies

$$\dot{v}_H^U = \dot{v}_L^U. \tag{34}$$

Now use (32), (34) and (30) for a skilled worker to rewrite (33) as

$$a_H \frac{\varepsilon_H}{s_H} = [\rho + k - (1-\alpha) g] C(H). \tag{35}$$

In (35), we also used the fact that $e = H$ in steady state. This is equivalent to (21) once (12) is substituted. Now, equation (21) links H and E_H such that $H = H(E_H)$ and

$$H'(E_H) = \frac{HC(H)}{E_H [(H - E_H) C'(H) + C(H)]} > 0. \tag{36}$$

Once $H = H(E_H)$ is substituted into the medium-run NSC (20), we obtain the long-run NSC (22). Next, for $\partial\omega_H/\partial E_H > 0$ in (22), it is sufficient to establish that $E_H/H(E_H)$ is increasing in E_H :

$$\frac{\partial}{\partial E_H}\left(\frac{E_H}{H(E_H)}\right) = \frac{1}{H}\left(1 - H'(H)\frac{E_H}{H}\right) \tag{37}$$

$$= \frac{(H - E_H) C'(H)}{H [(H - E_H) C'(H) + C(H)]} > 0 \tag{38}$$

where (36) is used in calculation. Note that if C is identical for all new born workers, then (21) implies that $H'(H) E_H/H = 1$, implying that the long-run NSC is horizontal (see (37)).

Appendix B

This appendix derives (23). For the threshold new born worker who are indifferent between being skilled and unskilled,

$$v_H^U - v_L^U = C(E_H) \tag{39}$$

must hold. This implies

$$\dot{v}_H^U = \dot{v}_L^U + \dot{E}_H C'(E_H). \tag{40}$$

Now use (32), (40) and (29) for a skilled worker to rewrite (39) as

$$\omega_H = [\rho + k - (1-\alpha) g] C(E_H) + z + \frac{\varepsilon_H}{s_H}(s_H + b_H) - \dot{E}_H C'(E_H). \tag{41}$$

This can be rearranged into (23), using (11).

Table 1: Changes in the college wage premium.

Country	Educational Groups	Ratio(Year)	Ratio(Year)	Ratio(Year)
Canada	University/High School	1.65 (1970)	1.39 (1980)	1.42 (1985)
Japan	College/Upper High School	1.33 (1970)	1.26 (1979)	1.26 (1987)
Sweden	University/Post Secondary	1.40 (1968)	1.16 (1981)	1.19 (1986)
UK	University/No Qualification	1.64 (1974)	1.53 (1980)	1.65 (1988)
US	College/High School	1.49 (1969)	1.36 (1969)	1.51 (1987)

Source:OECD Employment Outlook 1993, Table 5.6, Page 171

Table 2: Trends in the Relative Supply of College Graduates

Country	Educational Group	%(Year)	Ratio (Year)	Ratio (Year)
Japan	College	12 (1971)	17.9 (1979)	22.5 (1990)
Sweden	University	8.1 (1971)	16.6 (1980)	23.1 (1990)
UK	University	8.0 (1973)	12.0 (1979)	18.3 (1989)
US	College	10.8 (1969)	16.6 (1979)	21.5 (1989)

Source: OECD Employment Outlook, 1993, Table 5.7, Page 172.

Trends in Earnings Deciles

Table 3a - Trends in Canadian Earnings Deciles 1967-1994

Year	D1	D5	D9	D9/D5	D5/D1
1967	69	74	73	-	-
1973	102	95	95	-	-
1981	100	100	100	1.79	2.24
1986	91	98	100	1.83	2.43
1988	93	99	103	1.86	2.39
1990	94	100	103	1.85	2.38
1991	-	-	-	1.88	2.23
1992	-	-	-	1.82	2.33
1993	-	-	-	1.82	2.21
1994	-	-	-	1.84	2.28

Table 3b - Trends in French Earnings Deciles 1973-1994

Year	D1	D5	D9	D9/D5	D5/D1
1973	84	87	89	-	-
1974	87	89	92	-	-
1975	88	90	94	-	-
1976	95	96	98	-	-
1977	96	97	99	-	-
1978	101	101	102	-	-
1979	99	99	100	1.94	1.67
1980	100	100	100	1.93	1.69
1981	-	-	-	1.93	1.67
1982	102	101	101	1.94	1.65
1983	-	-	-	1.94	1.62
1984	104	101	101	1.93	1.60
1985	105	102	103	1.95	1.6
1986	108	104	106	1.96	1.62
1987	107	103	106	1.97	1.62
1988	107	103	104	1.97	1.64
1989	-	-	-	1.99	1.65
1990	-	-	-	1.99	1.64
1991	-	-	-	1.99	1.64
1992	-	-	-	1.97	1.64
1993	-	-	-	1.99	1.64
1994	-	-	-	1.99	1.65

Table 3c - Trends in Swedish Earnings Deciles 1968-1993

Year	D1	D5	D9	D9/D5	D5/D1
1968	57	65	71	-	-
1974	77	80	82	-	-
1980	-	-	-	1.57	1.3
1981	100	100	100	1.55	1.32
1982	-	-	-	1.53	1.31
1983	-	-	-	1.50	1.30
1984	106	105	104	1.52	1.33
1985	-	-	-	1.59	1.30
1986	110	110	108	1.57	1.32
1987	-	-	-	1.57	1.33
1988	115	114	112	1.56	1.34
1989	-	-	-	1.57	1.35
1990	-	-	-	1.52	1.32
1991	122	122	119	1.55	1.36
1992	-	-	-	1.57	1.34
1993	-	-	-	1.59	1.34

Table 3d - Trends in UK Earnings Deciles 1973-1995

Year	D1	D5	D9	D9/D5	D5/D1
1975	95	101	100		
1976	98	101	100		
1977	99	101	102		
1978	101	102	102		
1979	103	101	102	1.73	1.84
1980	100	100	100	1.76	1.85
1981	98	99	101	1.74	1.92
1982	97	98	103	1.80	1.97
1983	95	99	103	1.78	1.99
1984	92	99	102	1.86	1.98
1985	94	99	104	1.84	2.03
1986	94	103	107	1.87	2.07
1987	94	102	107	1.91	2.06
1988	93	103	107	1.99	2.05
1989	92	103	106	1.97	2.05
1990	-	-	-	1.96	2.02
1991	-	-	-	1.95	2.01
1992	-	-	-	2.00	2.04
1993	-	-	-	2.00	2.06
1994	-	-	-	2.01	2.13
1995	-	-	-	2.04	2.13

Table 3e - Trends in US Earnings Deciles 1975-1995

Year	D1	D5	D9	D9/D5	D5/D1
1975	95	101	100	-	-
1976	98	101	100	-	-
1977	99	101	102	-	-
1978	101	102	102	-	-
1979	103	101	102	1.65	1.69
1980	100	100	100	1.67	1.67
1981	98	99	101	1.73	1.68
1982	97	98	103	1.74	1.70
1983	95	99	103	1.75	1.70
1984	92	99	102	1.77	1.72
1985	94	99	104	1.77	1.73
1986	94	103	107	1.78	1.74
1987	94	102	107	1.81	1.77
1988	93	103	107	1.82	1.78
1989	92	103	106	1.83	1.79
1990	-	-	-	1.84	1.79
1991	-	-	-	1.85	1.77
1992	-	-	-	1.85	1.79
1993	-	-	-	1.86	1.79
1994	-	-	-	1.86	1.78
1995	-	-	-	1.87	1.81

Source: The first three columns are indices of real wages for the 1st, 5th and 9th earninsg deciles respectively. The data for these columns comes from the OECD Employment Outlook, 1993, Table 5.2, Page 159. The final two columns contain measures of relative earnings the the 9th relative to the 5th and the 5th relative to the 1st, earnings deciles. This data comes from the OECD Employment Outlook, 1996, Table 3.1, Page 62. The real wage data for the UK and the relative wage data for the US relate only to male employees. All other figures cover both men and women.

Table 4: Retention Rates by Educational Attainment

EducationalGroup	Australia	Canada	Germany	Japan	United States[20]
< Secondary					
1980 – 1985	–	50	–	64.6	52.2
1985 – 1990	41.3	43.5	69.1	62.1	55.2
1990 – 1995	49.4	42.3	54.4	62.2	46.7
Upper Secondary					
1980 – 1985	–	53.1	–	76.2	59.5
1985 – 1990	49.6	44.4	67.3	72.2	62.4
1990 – 1995	56.1	51.4	63.3	67.9	56.4
Tertiary Education (Non-University)					
1980 – 1985	–	–	–	71.7	54.9
1985 – 1990	47.6	–	80.0	70.3	61.4
1990 – 1995	24.6	59.1	80.0	66.6	57.6
Tertiary Education (University)					
1980 – 1985	–	–	–	85.4	64.4
1985 – 1990	44.2	–	70.8	76.8	63.4
1990 – 1995	54.6	65.6	78.6	77.5	61.8

Source: OECD, Employment Outlook 1997,Table 5.9 p142. The retention rates given in this table are five year retention rates - that is the percentage of workers of a given educational type in a certain year that will remain with the same employer five years from now.

Table 5: Unemployment Rates for persons aged 25-64, 1998 by educational attainment

Country	< Secondary	Upper Secondary	Tertiary
Australia	9.0	5.8	3.3
Canada	12.2	7.8	5.2
Germany	16.6	10.8	5.6
Japan	4.4	3.3	2.7
Sweden	10.4	7.2	3.6
United Kingdom	10.5	5	2.6
United States	8.5	4.4	2.1

Source: OECD Employment Outlook July 2000, Table D, page 215.

[20] For the united states the three time periods considered are 1979-1983, 1983-1987 and 1987-1991, respectively.

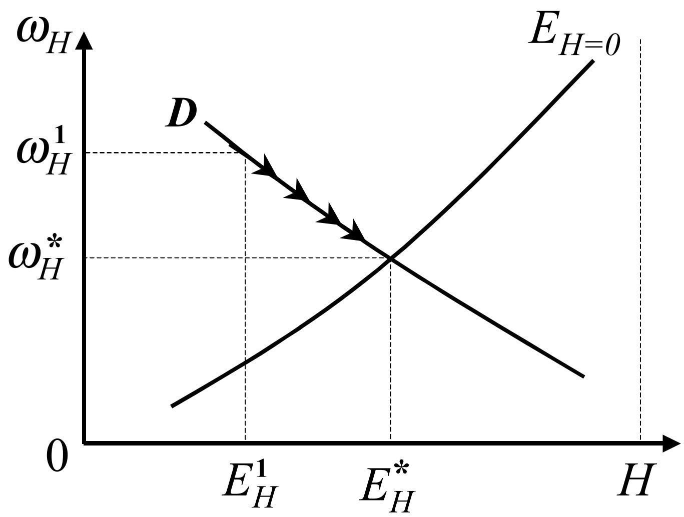

Figure 1: Equilibrium Level of Inequality.

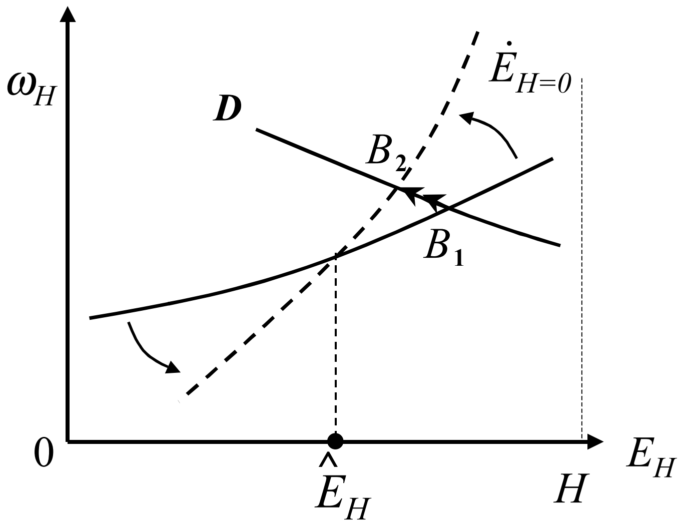

Figure 2: Inequality and an Increased Rate of Skill-Neutral Technical Progress

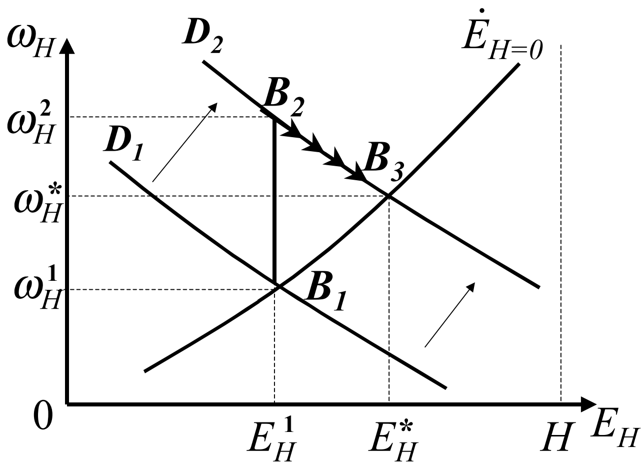

Figure 3: Inequality and Skill-Basied Technical Progress - Skilled Labour Market

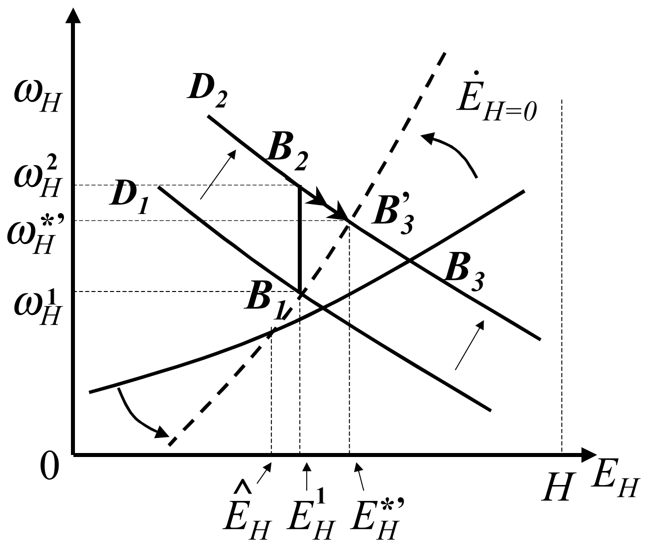

Figure 4: Inequality and an Acceleration in Technical Progress with a Bias Towards Skills

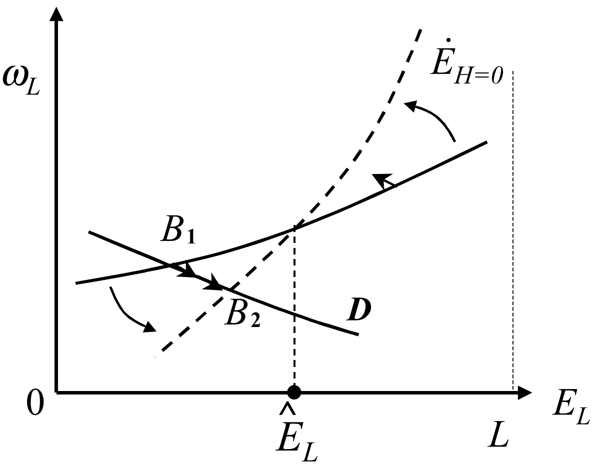

Figure 5: Low Skilled Wages and an Acceleration in Unbiased Technical Progress

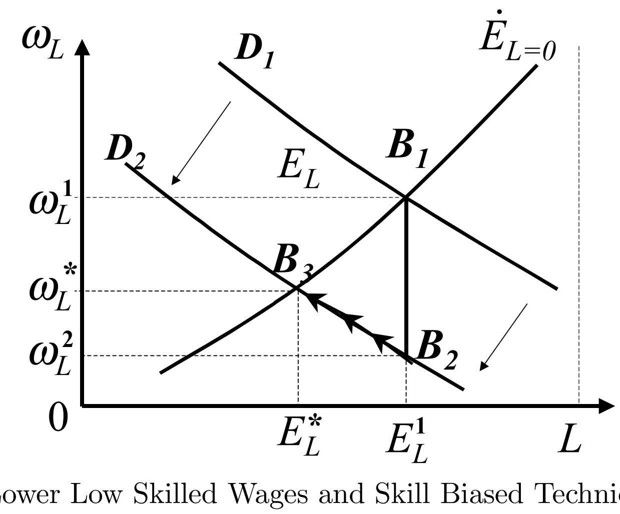

Figure 6: Lower Low Skilled Wages and Skill Biased Technical Progress

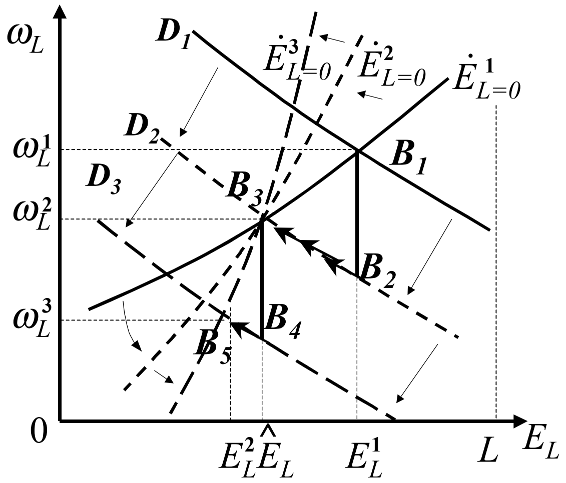

Figure 7: Continued Accelerated Skill-Biased Technical Progress.

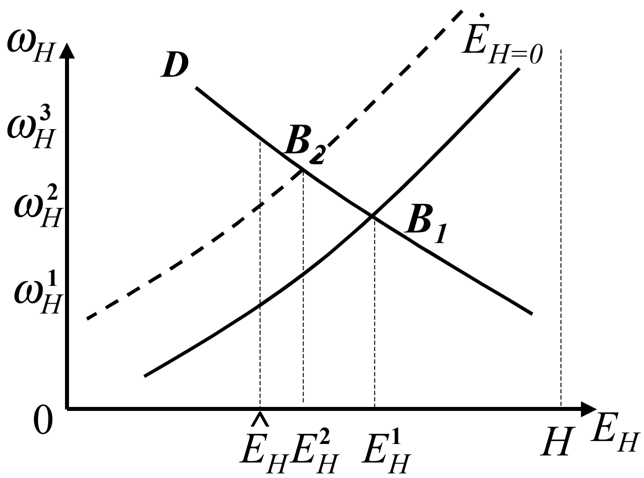

Figure 8: Policies Which Increase the Equilibrium Rate of Unemployment

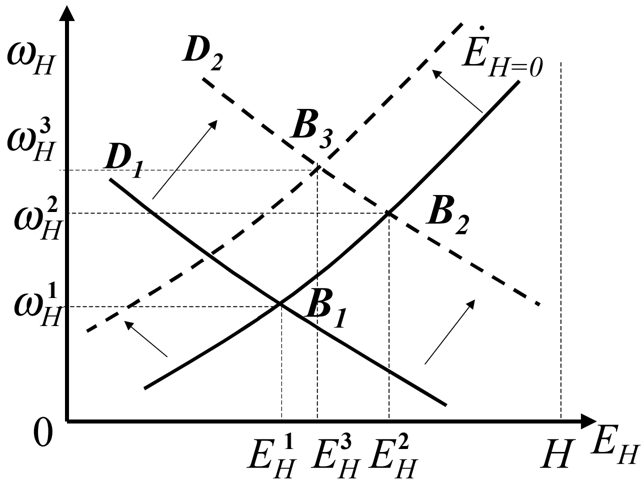

Figure 9: Skilled Wages, Skilled Biased Technical Progress and a Wealth Effect

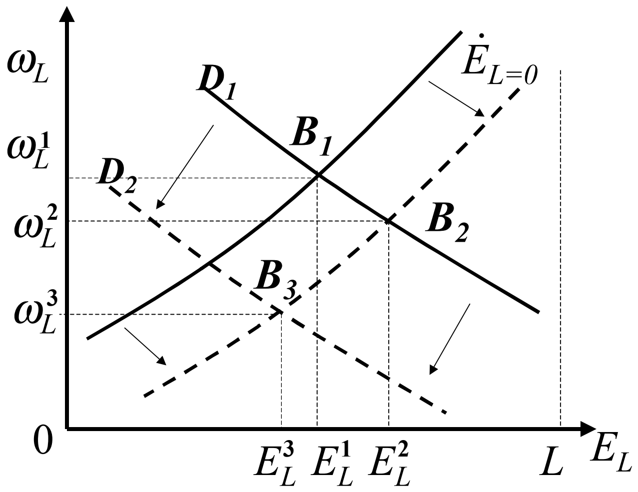

Figure 10: Low Skilled Wages, Skilled Biased Technical Progress and a Wealth Effect

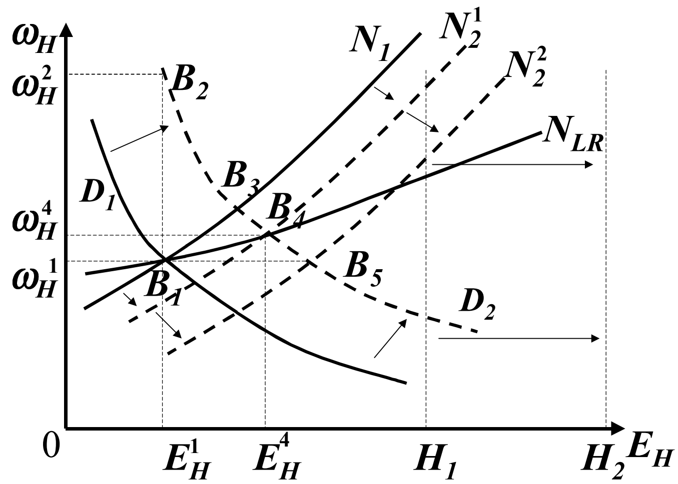

Figure 11: Endogenous Retraining and Inequality in the Long-Run. N_1represents the initial medium run NSC. N_{LR} is the long-run NSC with endogenous determination of H and heterogenous costs of educations. N_2^1 is the medium run NSC after H has been determined by N_{LR}. N_2^2 is the medium run NSC after H has been endogenously determined and all workers face the same costs of training.

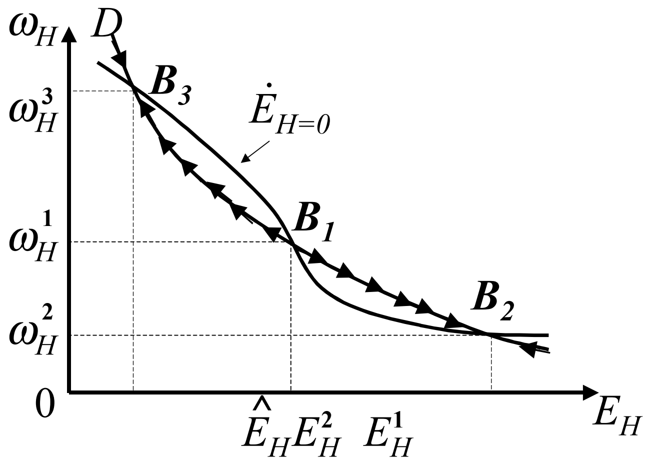

Figure 12: Multiple Equilibria

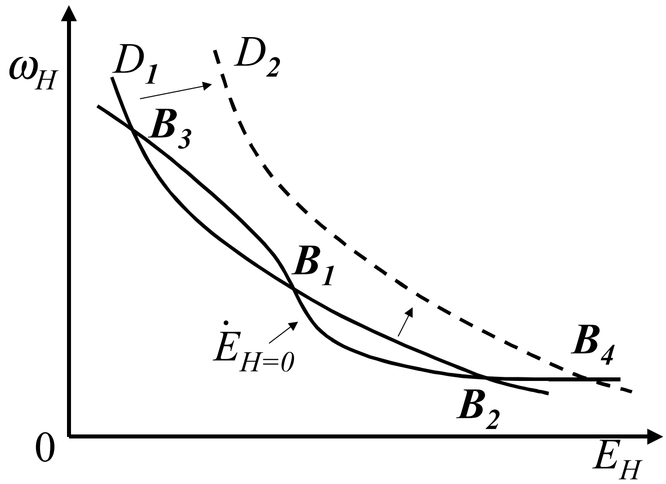

Figure 13: Skill Biased Technical Change

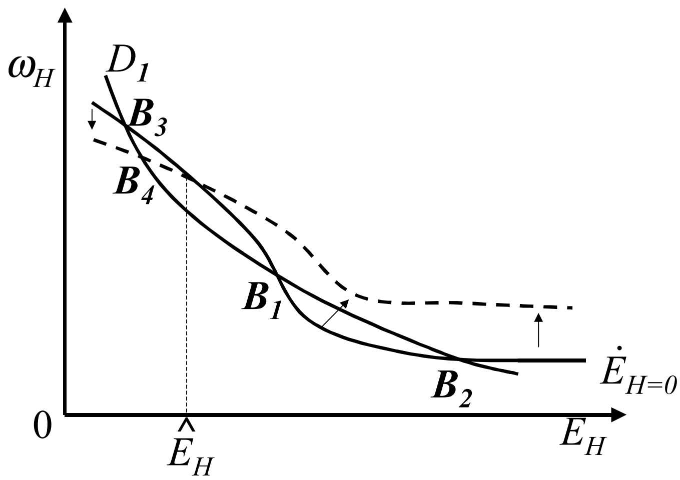

Figure 14: Acceleration in Skill-Neutral Technical Progress