



Working Paper Series

**Power-Biased Technological Change and the
Rise in Earnings Inequality**

Frederick Guy

Peter Skottz

ECINEQ WP 2005 – 06

Power-Biased Technological Change and the Rise in Earnings Inequality*

Frederick Guy

School of Management and Organizational Psychology, Birkbeck College

Peter Skottz[†]

Department of Economics, University of Massachusetts

Abstract

New information and communication technologies, we argue, have been ‘power- biased’: they have allowed firms to monitor low-skill workers more closely, thus reducing the power of these workers. An efficiency wage model shows that ‘power-biased technical change’ in this sense may generate rising wage inequality accompanied by an increase in both the effort and unemployment of low-skill workers. The skill-biased technological change hypothesis, on the other hand, offers no explanation for the observed increase in effort.

KEYWORDS: power-biased technical change, skill bias, efficiency wages, wage inequality, work intensity.

JEL Classification: J31, O33

* An early version of this paper was presented at a conference in honour of John Roemer, University of Massachusetts, Amherst, May 2005. We are grateful to our discussant Bill Gibson as well as conference participants for helpful comments and suggestions

[†] **Contact details:** Frederick Guy School of Management and Organizational Psychology, Birkbeck College, Malet St, London WC1E, 7HX, UK; f.guy@bbk.ac.uk // Peter Skottz Department of Economics, University of Massachusetts, Amherst, MA 01003, USA; pscott@econs.umass.edu

1 Introduction

Earnings inequality in the United States and other liberal market economies rose considerably from the late 1970s through the early 1990s (Gottschalk and Smeeding 1997). Explanations for this change include institutional change (DiNardo, Fortin, and Lemieux 1996), increased openness to trade (Leamer 1996) , and technological change (Berman, Bound, and Machin 1998). This paper is about how to understand the contribution of technological change, and in particular the adoption of new information and communications technologies (ICTs).

In the economics literature, the contribution of new technology to earnings inequality has most often been explained in terms of the supply and demand for skill, under the heading skill-biased technological change (SBTC). An alternate hypothesis locates the connection in a change in the parameters of agency problems within the firm. We explore the latter hypothesis with the aid of an efficiency wage model. In such models, earnings are determined by a combination of market conditions and the employee's ability to affect the employer's outcomes through a choice of actions, or effort. Viewing this ability as a form of power, we shall refer to this alternate explanation for increased earnings inequality as power-biased technological change (PBTC) .

The rest of this paper is organized as follows. In Section Two we review the problem of distinguishing, empirically, between SBTC and PBTC. Section Three presents an efficiency wage model in which we show that the power bias hypothesis is consistent not only with reduced earnings for the less skilled, but also increased work effort and reduced employment. Section Four considers the policy implications. Section Five concludes.

2 Distinguishing skill bias and power bias.

When employers adopt new technologies, jobs change in various ways. We want to distinguish between two sorts of change, changes in skill requirements and changes in employee power, as defined above. All jobs entail some power: an investment banker makes investments which may make or lose millions for the bank, and a burger flipper can burn a few batches of burgers; the difference in degree is important, but in both cases there is an agency problem with which the employer must reckon. Among the factors which determine the employee's power are the extent of the assets or operations concerning which the employee makes decisions; the quality and timeliness of the employer's information about the employee's actions; and the quality and timeliness of the employer's information about the situation in which the employee acts (the 'state of nature'). Each of these parameters of employee power will be affected by changes in ICT, either through direct application of the technology (e.g., monitoring), or through ICT-facilitated changes in jobs and organization structure.

The adoption of new technologies can also affect the demand for skills, increasing demand for some skills and reducing the demand for other skills, or for less-skilled labor.

It is commonly argued that new technologies have been skill-biased in this sense. SBTC combined with a lag in the adjustment of the skill supply (or a simple failure of the skill supply to adjust) can lead to a rise in earnings inequality. By analogy, we apply the term power-biased technological change (PBTC) to a situation in which changes in technology lead to changes in workplace power. Technological changes that generate a general shift in the power of all workers vis-a-vis firms represent a kind of power bias and we shall consider this scenario briefly in Section 4. But the main focus in this paper is on changes in the relative power of different groups of workers and especially on technological changes that increase the power of high-paid workers and reduce that of low-paid workers. A priori, of course, it is not obvious that ICT must involve a power (or skill) bias that favors relatively powerful (high-skilled) workers, but this case is the relevant one for an explanation of the observed increase in inequality.

In terms of formal models of earnings determination, the distinction between skill and power is clear: for skill, we have straightforward models of supply and demand equilibrium in the market for human capital; for power, we have a variety of principal-agent models. Yet the two have often been conflated. For instance, Braverman (1974) depicts de-skilling as a process driven by the employer's objective of dis-empowering employees, with the aim of paying them less. Yet de-skilled employees can become powerful, as the history of industrial unions testifies; and skilled employees are not necessarily powerful, as the experience of countless cooks, musicians, garment makers and horticulturalists shows. Power on the job is correlated with skill – other things equal, when the employer has a choice, more consequential discretion will be given to employees who know well what they are doing, than to those who do not – but it is not the same as skill, and factors other than skill are involved in the determination of power.

Empirical studies of the causes of inequality have a difficult time distinguishing skill from power, not just because of the possible conceptual conflation but because of inadequate data. Measurements of either property are at best incomplete, and are more often indirect. Sometimes the proxies used are equally well proxies for skill and power. After a number of studies proxying skill with the use of a computer at work had found that ICT-related skills led to higher pay (see Autor, Katz, and Krueger 1998, and references therein), DiNardo and Pischke (1997) found that German workers received similar pay premiums for using computers and for using pencils; they also got paid more for sitting rather than standing. DiNardo and Pischke do not leave us believing that we know what causes pay differentials, but the fortuitous inclusion of pencils alongside computers in their data does tell us something of the limits of our knowledge. Or consider the evidence presented by Entorf and Kramarz (1997). Using longitudinal data on individual earnings, technology and the amount of discretion afforded employees in a broad sample of French companies, they find an earnings premium for the use of new technology, but only if the job allows significant discretion. This is consistent with a power interpretation, but we lack direct information on skill differences.

Most of the sector or industry-specific research on earnings differentials has dealt with

manufacturing, which is better documented and, historically, more trade-sensitive. There are, however, a number of studies of the effect of ICTs on the labor process in growing industries such as retailing, banking, telecommunications and customer service call centers. These studies provide evidence for the view that a widening of workplace power differences following the adoption of ICTs is quite common, if by no means universal. Significant populations of lower-paid workers face increased monitoring, more precise task specification, and reduced opportunity for promotion, while managers face more consequential choices as a result of increased organizational flexibility. To the extent these studies deal with skill, however, skill differentials appear to be widening, too, so again the results are suggestive, but not decisive (Grimshaw et al. 2002; Grimshaw et al. 2001; Miozzo and Ramirez 2003; Batt 2001; Sewell 1998; Hunter and Lufkas 2003).

Why it is so difficult to sort out the power and skill effects can be seen clearly if we consider some particular cases. We might be able to find a few pure cases of power or skill change. For instance, if so many electric typewriters with correction ribbons replace so many manual ones, there is a change in capital-skill complementarity (because the new capital is more forgiving of mistakes, the marginal product of typing skill is less), but no change in power that we can think of. Or, consider the case of truck drivers: prior to the 1980s a truck driver's employer usually had only a vague idea of where the driver and truck were. Now the location of the truck, and even the behavior of its engine, are often tracked by satellite. The skills required of the driver have not changed, but his scope for taking advantage of possible slack in his schedule is diminished, and the employer has new information with which to remove slack from the schedule over time. In this case, there is no change in capital-skill complementarity, but there is a change in power.

Such pure cases are, however, exceptional. More often, there are good reasons to believe that technological change affects both the skill requirements of a job, and the power associated with the job. For instance:

(1) *Bar-code scanners in retailing.* For roughly a century, from the 1880s to the 1980s, a cash register kept track of the total amount of money the operator had taken in from customers, and were able to subtotal this by department within the store. As a technology of control, the cash register had the following limitation: while it helped to ensure that the cash collected from customers was the same as the cash delivered by the cashier to the employers, it could not prevent cashiers from under-charging favored customers (friends, relatives), a phenomenon which was euphemistically referred to in the retail trade as 'under-ringing'. Efficient operation of the cash register also required certain motor and cognitive skills.

With the introduction of bar code scanners, both the power and the skill requirements of being a retail cashier changed simultaneously: under-ringing became far more difficult, and the skills required to operate a cash register became considerably less.

(2) *High involvement work practices (HIWPs)*, such as self-managed teams, employee involvement in decisions, multi-skilling of workers, and flattening of hierarchies. Like Bres-

nahan (1999), we regard the spread of HIWPs as a consequence of technological change. One reason for this is that HIWPs are facilitated by modern ICTs. Another is that HIWPs are part of a strategy of output flexibility and responsiveness to customers which is itself made possible by flexible production technologies. Whatever the reasons, technological change and the adoption of HIWPs appear to be complements (Piva, Santarelli, and Vivarelli 2005).

The evidence on whether HIWPs lead to higher pay is mixed, but on the whole it favors the proposition that they do so. In recent multi-industry studies, Forth and Millward (2004) find that they do raise pay in the UK, while Handel and Gittleman (2004) conclude that they do not in the US. We have reason to doubt Handel and Gittleman's interpretation of their results, however: they actually report substantively, and sometimes statistically, significant estimates of higher wages associated with some particular HIWPs; this despite the fact that the pooling of dissimilar industries and errors in the measurement of the use of work practices both bias their estimates toward zero. Hunter and Lafkas (2003) avoid much of this bias by studying a particular US industry (banking), and do find a positive association between HIWPs and employee earnings. Guy (2003) examines reasons for a positive relationship between HIWPs and earnings in supermarkets.

HIWPs may involve changes in both skill and power. Teamwork, for instance, is an area in which demand for skill and employee power are hard to distinguish. In many workplaces, workers who once had narrowly defined individual jobs now do all or part of their work in teams; a worker may be expected to do a number of different jobs within the team, and some teams are assigned problem-solving or decision-making responsibilities which were not previously within the remit of employees at their level. Such teamwork may enhance the scope of action open to a worker, both because of the broadening of tasks (e.g., 'problem solving'), and what may be the greater difficulty of assigning individual accountability when actions are taken by teams. On the other hand, improvements to the employer's information systems may offset this empowerment: improved planning and monitoring may reduce the scope of employee decisions.

Skill requirements may also increase for workers involved in HIWPs, partly because of multiple-skill requirements, and partly because teamwork is said to require particular social skills (Bresnahan 1999; Bresnahan, Brynjolfsson, and Hitt 2002). What are labeled social skills, however, can also be viewed as propensities to behave in certain ways. Such propensities, or personality traits, may (like skills) be a product of the education system, and are an attribute which employees bring with them to jobs (Bowles and Gintis 1976). But propensities are not skills, and if these particular social propensities have become more important to employers, this suggests that a failure to behave in line with such propensities would now be more costly to an employer than it would have been before; if this is so, then the increased importance of 'social skills' or personality characteristics may be an indication of increased employee power.

(3) *Changes in managerial work.* The de-layering of organizations and the competitive need for organizations to be flexible give the remaining managers a greater range

of decisions to make. On the other hand, managers get monitored, too. It is tempting, especially for those of us trained to recognize the beauty of markets as examples of spontaneous, un-regimented order, to associate delegation, de-layering and decentralization as marketization, the sunset of central control. But within organizations, decentralization is typically facilitated by improved controls. For instance, the invention of the multi-divisional corporation in the 1920s was made possible by improved cost accounting and 'management by numbers' (Chandler 1962, Auerbach 1988). The change in the power of individual managers is therefore indeterminate. And, of course, organizational flexibility may increase the demand for skill among managers.

On the whole, then, distinguishing between the effects of skill-bias and those of power-bias is not straightforward. Even findings in the research on earnings inequality which seem to favor either skill-bias or power-bias can be less clear-cut than may first appear. The simultaneous increase in the relative wage and the relative employment of high-skill workers, for instance, is an important piece of evidence for the SBTC explanation (Berman, Bound, and Griliches 1994; Berman, Bound, and Machin 1998; Davis and Haltiwanger 1991), but our formalization in section 3 shows that a power bias may also account for this evidence.

The exploration of PBTC in this paper is related to recent work by Green (2001, 2004). Green shows that levels of effort at work in UK firms increased during the 1990s, and a larger body of research (also reviewed by Green 2004) supports this finding of increased effort in the UK, and probably in other industrial economies, during the 1980s and 1990s. The standard SBTC approach sheds little light on these findings. Based on his econometric results, however, Green attributes a large part of the rise in effort to technological changes. These changes, he argues, may have improved the capacity of managers to monitor effort and / or, as a second channel, they may have been "effort-biased", that is, they may have generated efficiency gains associated with better control of work flows, and these gains increased the marginal productivity of effort (Green 2004, p. 714). Both of the channels identified by Green can be seen as examples of technology affecting employee power (for a given level of monitoring, a change in the marginal product of effort changes the employee's ability to affect employer outcomes).¹ Green does not, however, consider the differential effects of technological change on wage inequality and the relative effort of different groups of workers. Moreover, he eschews formal modeling, suggesting (quite rightly) that there is a multiplicity of possible explanations of increased effort and that these "explanations operate in a range contexts (including competitive, bilateral bargaining and efficiency wage models)" (Green 2004, p. 712). But general reduced-form relations also have obvious drawbacks. Our aim in this paper is to examine a particular case of PBTC - improved monitoring of lower paid workers - and its implications, and for this purpose a formal model is needed.²

¹Green's (2004) study also explores various other possible inducements to greater effort.

²It should be noted that while "effort-biased technical change" is consistent with the PBTC model

3 A formal model of power-biased technical change

We use a standard efficiency wage framework to analyze the effects PBTC, and to keep the analysis simple consider an economy with only two types of workers. We assume that there is no heterogeneity among workers of a given type and that employed workers always hold jobs that match their type.³ It may be reasonable to suppose that the two types of workers are defined by their different skills, but from a technical perspective the key assumption is just the separation of workers into two distinct pools, each with its own unemployment rate. All firms are identical and, disregarding non-labor inputs, output of the representative firm is given by

$$Y = AF(e_H N_H, e_L N_L)$$

where e_i and N_i denote effort and employment of type i workers, $i = H, L$ (H =high power, L =low power). Our concern in this paper is with the effect of changes in the ability of firms to affect employee power in one particular way, which is to monitor effort. In order to focus on this aspect of the problem we assume complete symmetry between the two groups of workers, except for differences in the monitoring of the two groups. One aspect of the symmetry assumption is that of neutral technical change, that is, we assume while the productivity parameter A may change, the F -function remains unchanged. This definition of Hicks-neutrality when effort is endogenous is discussed further in Appendix A.

Workers' choice of effort is determined by the cost of job loss and the sensitivity of the risk of job loss to variations in effort.⁴ As a formal specification, we assume that if a firm pays the wage w_i , the effort of its type- i workers may be determined by the maximization of the objective function V^i ,⁵

$$V^i = p^i(e_i)[w_i - v(e_i) - h^i(\bar{w}_i, b, u_i)] \quad (1)$$

where \bar{w}_i, u_i and b denote the average wage, the unemployment rate and the rate of unemployment benefits. Arguably the choice of effort should be determined by an optimization problem that is explicitly intertemporal but as shown in Appendix B, a simple intertemporal optimization model reduces to a special case of problem (1).

(which assumes an incomplete contract for effort), it is also consistent with a model of complete contracts and an unequal distribution of the ability or willingness to work at a high level of effort.

³A significant amount of evidence suggests that this assumption may be misleading. Skott (2005, 2006) and Skott and Auerbach (2005) analyse alternative models in which unemployed high-skill workers may accept low-skill jobs. We shall return to this issue in Section Four.

⁴Most expositions of efficiency wage models emphasize the former effect, with the risk of job loss and its dependence on effort taken as exogenous; exceptions include Bowles (1985) and Gintis and Ishikawa (1987).

⁵We use subscripts ($i = H, L$) for variables but superscripts for functions since, in accordance with standard practice, subscripts denote partial derivatives in the case of functions.

The function $v(e_i)$ describes the disutility associated with effort, and the function $p^i(e_i)$ captures the effect of effort on the expected remaining duration of the job; since an increase in effort raises the disutility of effort and reduces the risk of being fired, we have $v' > 0, p^{i'} > 0$. By assumption there is symmetry between the two groups, except for power differences, and the v -function is therefore the same for both groups of workers. The function $h^i(\bar{w}_i, b, u_i)$ represents the fallback position, that is, the expected utility in case of job loss; the partial derivatives satisfy $h_{\bar{w}}^i > 0, h_b^i > 0$ and $h_u^i < 0$ under all standard assumptions.

The first order condition for the worker's maximization problem can be written

$$-p^i v' + (w_i - v - h^i) p^{i'} = 0 \quad (2)$$

and we may write the solution to the problem as

$$e_i = f^i(w_i, \bar{w}_i, b, u_i) \quad (3)$$

The sign of the partial f_w^i must be positive at any wage (above the minimum) chosen by a profit maximizing firm and, using the second order condition in combination with the partials for h^i , it is straightforward to show that $f_{\bar{w}}^i < 0, f_b^i < 0, f_u^i > 0$.

Now introduce the effect of technical change on firms' ability to monitor effort. This change may be represented by a shift in the p^i -function. The crucial element of this shift is that it affects the *sensitivity* of the firing rate to variations in effort. Thus, we assume that

$$\frac{p^{i'}}{p^i} = \lambda(e_i, \mu_i) \quad (4)$$

where the parameter μ_i describes monitoring ability and $\lambda_\mu > 0$. An improvement in firms' ability to monitor the efforts of individual workers makes the expected job duration of any individual worker more sensitive to changes in the worker's own effort. Equation (4) expresses this assumption. It should be noted, however, that the equation says nothing about the average firing rate and, as explained in appendix B, the average firing rate may be unaffected by a change in μ_i .

Totally differentiating the first order condition (2) and using (4) we get

$$e_{i\mu} = \frac{\partial e_i}{\partial \mu_i} = -\frac{\phi_\mu^i}{\phi_e^i} > 0$$

where $\phi^i = -p^i v' + (w_i - v - h^i) p^{i'} = p^i [-v' + (w_i - v - h^i) \lambda]$. Using the first order condition, we have $\phi_\mu^i = p^i (w_i - v - h^i) \lambda_\mu + p_\mu^i [-v' + (w_i - v - h^i) \lambda] = p^i (w_i - v - h^i) \lambda_\mu > 0$, and the sign of $e_{i\mu}$ now follows from the second-order condition which implies that ϕ_e^i is negative. Intuitively, if the cost of job loss is positive and the expected job duration becomes more sensitive to variations in effort, the optimal response is to raise effort.

The wage is set by the firm. The standard first order conditions imply that

$$\frac{e_{iw} w_i}{e_i} = 1 \quad (5)$$

and, using (3)-(5), the solutions for wage and effort can be expressed⁶

$$\begin{aligned} w_i &= w_i(\bar{w}_i, u_i; \mu_i) \\ e_i &= e_i(\bar{w}_i, u_i; \mu_i) \end{aligned}$$

In equilibrium, $w_i = \bar{w}_i$ and

$$w_i = w_i(u_i; \mu_i), \quad i = H, L \quad (6)$$

$$e_i = e_i(u_i; \mu_i), \quad i = H, L \quad (7)$$

Combining equations (6)-(7) with firms' first order conditions with respect to employment, we get

$$w_i = e_i A F_i(e_L N_L, e_H N_H) \quad (8)$$

Using the definitional relations between unemployment u_i and employment N_i , equations (6)-(8) yield equilibrium solutions for the endogenous variables (w_i, e_i, N_i) as functions of the parameters A and μ_i that describe the technology:

$$N_i = N_i(A, \mu_i, \mu_j), w_i = w_i(N_i, \mu_i) = w_i(A, \mu_i, \mu_j), e_i = e_i(N_i, \mu_i) = e_i(A, \mu_i, \mu_j)$$

where $i = H, L; j = H, L; i \neq j$.

Definite conclusions concerning the effects of a changes in power (changes in the parameters μ_i) can be obtained if functional forms for the h -, p - and v -functions are introduced. We assume that the p - and v -functions satisfy

$$\frac{p^{i'}}{p^i} = \lambda(e_i, \mu_i) = \frac{\mu_i}{e_i} \quad (9)$$

$$v(e_i) = e_i^\gamma, \gamma > 1 \quad (10)$$

The specification of the semi-elasticity of the p^i -function in (9) can be seen as a log-linear approximation of the p^i -function around the equilibrium solution for e_i .⁷ Equation (10) is standard, the parameter restriction $\gamma > 1$ implying that given the chosen scale of effort, the disutility of effort is strictly convex.⁸ This convexity assumption ensures that the firm's unit cost does not decrease monotonically as wages increase and that, therefore, an equilibrium solution for w exists.

⁶Unemployment benefits are taking to be constant throughout the analysis, and the variable b is therefore omitted from the expressions.

⁷Integration of (9) implies that

$$p^i(e_i) = K e_i^{\mu_i}$$

where K is an arbitrary constant. The intertemporal interpretation in Appendix B of workers' maximisation problem implies that $p^i(e_i)$ is bounded, unlike the above expression. Thus, the approximation will be bad for 'large' values of e_i . It may be good, however, for effort levels in the relevant range, and all our simulations below yield modest variations in effort.

⁸Effort is ordinal and the convexity assumption is conditional on the chosen scale. This scale is determined implicitly by the specification of the production function (Katzner and Skott (2004)).

The specification (9)-(10) implies that (6)-(7) take the following form (see Appendix C)

$$e_i = \left[\frac{\mu_i}{\mu_i + \gamma} \frac{1}{\gamma - 1} h_i \right]^{1/\gamma} \quad (11)$$

$$w_i = \frac{\gamma}{\gamma - 1} h_i \quad (12)$$

With respect to the fallback position, finally, we use the specific functional form obtained from the optimization model in Appendix B:

$$h^i = \frac{(r + \delta)u_i}{ru_i + \delta} b + \frac{\delta(1 - u_i)}{ru_i + \delta} (\bar{w}_i - v(\bar{e}_i)) \quad (13)$$

where \bar{e}_i is determined by setting $w_i = \bar{w}_i$ in equation (3); r and δ are the discount rate and the rate of job separations, respectively. The symmetry assumption implies that both groups have the same discount rate, and the average rate of separations may be also the same for both groups even if their power and effort levels differ (see Appendix B). Intuitively, the fallback position is a weighted average of the utility when unemployed (b) and in an alternative job ($\bar{w}_i - v(\bar{e}_i)$). The weights depend on u_i since (in a steady state) the unemployment rate is equal to the proportion of time one can be expect to unemployed; if there is no discounting ($r = 0$) the weights are simply u_i and $1 - u_i$ but when $r > 0$, unemployment (the initial state in case of job loss) is weighted more heavily.

Turning to the demand for labor, we assume a symmetric CES production function,

$$Y = A[0.5(e_L N_L)^{-\rho} + 0.5(e_H N_H)^{-\rho}]^{-1/\rho}$$

where $\sigma = 1/(1 + \rho)$ is the elasticity of substitution. This specification implies that equations (8) can be written

$$\begin{aligned} w_i &= A[0.5(e_L N_L)^{-\rho} + 0.5(e_H N_H)^{-\rho}]^{-(1+\rho)/\rho} (0.5) e_i^{-\rho} N_i^{-(1+\rho)} \\ &= 0.5^{-1/\rho} A e_i [1 + \left(\frac{e_j N_j}{e_i N_i}\right)^{-\rho}]^{-(1+\rho)/\rho} \end{aligned} \quad (14)$$

With symmetric and inelastic labor supplies (normalized at unity), finally, we have

$$u_i = 1 - N_i \quad (15)$$

The solutions for $(e_L, w_L, N_L, e_H, w_H, N_H)$ can be derived using (11)-(15). Not surprisingly, the fully symmetric case with $\mu_L = \mu_H$ produces a symmetric solution for effort, wages and employment: $(e_L, w_L, N_L) = (e_H, w_H, N_H)$.

In order to analyse the implications of power-biased change in monitoring technology we now introduce a decline in the power of low-power workers (a rise in μ_L) and / or an increase in the power of high-power workers (a fall in μ_H). Consider a rise in μ_L . Intuitively,

this rise puts upwards pressure on e_L (equation (11)) and thus, for a given value of N_L , on the effective labor input $e_L N_L$. For a given ratio of relative labor inputs, $(e_L N_L)/(e_H N_H)$, a rise in e_L will increase the wage w_L (equation (14)), but w_L is affected negatively if the upwards pressure on $e_L N_L$ generates a rise in the input ratio $(e_L N_L)/(e_H N_H)$ (equation (14)). This negative effect is stronger the larger is ρ , that is, the lower the elasticity of substitution. Strong complementarity between the inputs also implies that any rise in e_L tends to affect N_L negatively (since the complementary demand for $e_H N_H$ following a rise in $e_L N_L$ raises high-power wages). Thus, the elasticity of substitution plays a critical role for the effects of a change in relative power.

It is readily seen that if the two types of workers are perfect substitutes ($\rho = -1$), both the wage w_L and employment N_L must increase following a rise in μ_L (see Appendix D). But perfect substitution is an extreme case. We know of no attempts to examine the elasticity of substitution between groups with different workplace power. As argued in Section Two, however, power and skill may be strongly correlated, and the estimates of the elasticity of substitution between different skill categories presented by Card, Kramarz and Lemieux (1999) are all very low. Thus, the empirically interesting case is likely to be one in which the elasticity of substitution is below unity, that is, $0 \leq \rho$. The implications of changes in μ_L are explored in Table 1 for different, non-negative values of ρ ; Table 1a assumes a Cobb-Douglas production function ($\rho = 0$) while Tables 1b-1d introduce complementarity ($\rho = 1, \rho = 4$ and $\rho = 10$, respectively). The variations in μ_L are within (what we consider) its plausible range. The intertemporal interpretation in Appendix B implies that $p = 1/(r + \delta)$ and hence that $p'/p = -\frac{1}{r+\delta} \frac{d\delta}{de} = -\frac{\delta}{r+\delta} \frac{1}{e} \frac{d \log \delta}{d \log e}$ where δ is the rate of job separations. Job separations happen for a range of reasons (including voluntary quits and plant closures), and it seems unlikely that $-\frac{d \log \delta}{d \log e}$ should exceed unity (this statement is meaningful since the chosen scale for effort implies that productivity is proportional to effort). It follows that μ will be less than one. Thus, we focus on the range $0 \leq \mu_L \leq 1$. With respect to the other parameters of the model, we use a discount rate of $r = 0.05$ and a rate of separations of $\delta = 0.2$ (implying that just over 18% of workers will lose, or choose to leave, their jobs within one period). The rate of unemployment benefits is normalized at one, $b = 1$, the productivity parameter is $A = 10$, and the (inverse) indicator of the power of high-power workers is $\mu_H = 0.1$. The parameter γ in the utility function, finally, must be greater than one (cf above), and the qualitative results appear to be insensitive to the precise value. The tables use $\gamma = 5$.

Table 1: Effects a decline in the power of L-workers
on effort, wage and unemployment

1a: Cobb-Douglas, $\rho = 0$										
μ_L	e_L	w_L	u_L	h_L	x_L	e_H	w_H	u_H	h_H	x_H
0.1	0.45	4.45	0.21	3.56	3.73	0.45	4.45	0.21	3.56	3.73
0.5	0.63	5.35	0.19	4.28	4.47	0.46	5.42	0.20	4.34	4.56
1.0	0.72	5.73	0.18	4.58	4.78	0.47	5.90	0.20	4.72	4.95

1b: Weak complementarity, $\rho = 1$										
μ_L	e_L	w_L	u_L	h_L	x_L	e_H	w_H	u_H	h_H	x_H
0.1	0.45	4.45	0.21	3.56	3.73	0.45	4.45	0.21	3.56	3.73
0.5	0.61	4.65	0.20	3.72	3.89	0.47	6.00	0.20	4.80	5.03
1.0	0.69	4.63	0.19	3.70	3.86	0.48	6.73	0.19	5.38	5.65

1c: Strong complementarity, $\rho = 4$										
μ_L	e_L	w_L	u_L	h_L	x_L	e_H	w_H	u_H	h_H	x_H
0.1	0.45	4.45	0.21	3.56	3.73	0.45	4.45	0.21	3.56	3.73
0.5	0.58	3.68	0.22	2.95	3.08	0.48	6.76	0.19	5.40	5.67
1.0	0.64	3.24	0.21	2.59	2.70	0.50	7.71	0.19	6.16	6.47

1d: Very strong complementarity, $\rho = 10$										
μ_L	e_L	w_L	u_L	h_L	x_L	e_H	w_H	u_H	h_H	x_H
0.1	0.45	4.45	0.21	3.56	3.73	0.45	4.45	0.21	3.56	3.73
0.5	0.56	3.12	0.23	2.50	2.61	0.49	7.18	0.19	5.74	6.02
1.0	0.61	2.55	0.25	2.04	2.12	0.50	8.11	0.19	6.49	6.81

As indicated in Table 1, a decrease in the power of the low-power workers benefits the high-power workers in terms of both wages and employment. Their effort also goes up but the net welfare effect can be calculated if one accepts the assumptions underlying the intertemporal optimization in Appendix B. Given these assumptions, the welfare of unemployed and employed workers can be measured by $h(= rU)$ and $x = (w - e^\gamma) \frac{r}{r+\delta} + h \frac{\delta}{r+\delta} (= rV)$, respectively.⁹ For high-power workers, the overall effect is an increase in both h_H and x_H for all values of ρ .

Low-power workers also benefit from an erosion in their own power if the production function is Cobb-Douglas and the power of high-power workers is unchanged. Low-power workers increase effort but employment and wages improve, and both h_L and x_L increase. Thus, the net benefits are unambiguously positive. This result may seem counter-intuitive at first sight but the explanation is straightforward. Agency problems lead to outcomes

⁹The values of h_i are proportional to w_i (cf. equation (12)). Separate h_i columns are included in the table to facilitate a comparison between the welfare measures for employed and unemployed workers.

that are Pareto suboptimal, and the increased ability of firms to monitor effort reduces the agency problem. Taking into account the derived effects on employment and wages, workers may therefore in some cases benefit from a decline in their workplace power. Table 2 presents a case in which the improved monitoring of one group of workers is combined with reduced monitoring of the other group. This case does not produce the same alleviation of the overall agency problem and, as a result, the loss of power generates a decrease in welfare for the low-power group.

Table 2: Effects of PBTC on effort, wage and unemployment in the Cobb-Douglas case when the rise in μ_L is combined with a fall in μ_H .

μ_L	μ_H	e_L	w_L	u_L	h_L	x_L	e_H	w_H	u_H	h_H	x_H
0.5	0.5	0.65	6.53	0.18	5.22	5.46	0.65	6.53	0.18	5.22	5.46
0.8	0.3	0.71	6.43	0.18	5.15	5.37	0.59	6.54	0.19	5.23	5.47

Returning to the case in which μ_H remains unchanged, Tables 1b-1d show how the improvements in employment and wages are eroded as the degree of complementarity in production increases. With weak complementarity ($\rho = 1, \sigma = 0.5$) the wage as well as the utility variables h_L and x_L move non-monotonically as the power indicator μ_L changes. When $\rho = 4$, unemployment changes non-monotonically but both the wage and the welfare measures h_L and x_L fall as μ_L increases. In the case with very strong complementarity ($\rho = 10$ and $\sigma \approx 0.9$) conditions deteriorate along all three dimensions, and the welfare measures h_L and x_L decline strongly when μ_L increases.

This simple model can yield outcomes that are broadly in line with US and UK experience. Consider for instance, an increase in μ_L from 0.5 to 1. If $\rho = 1$, perhaps the most plausible estimate, effort (=productivity) increases by about 10 percent for the low paid workers, their real wage declines slightly, their relative wage falls by about 12 percent, and the relative unemployment rates remain roughly unchanged. One should not, of course, read too much into this broad congruence with empirical observations. We certainly do not claim that the model (and PBTC, more generally) provides an adequate explanation of the movements in wage inequality. The results of the simulations do show, however, that the effects of PBTC can be quantitatively important.

4 Implications

If technological changes lie behind the observed movements in wage inequality, does it matter whether the technical change is skill biased or power biased? The answer is yes. Greater precision, first, is always desirable. The SBTC hypothesis arguably has often been presented in a rather vague manner, and empirically it has been difficult to identify the critical changes in skill requirements. If nothing else, the distinction between PBTC and SBTC may help to clarify some aspects of the changes that have been taking place in the labor market.

The source of the bias, second, may have implications for the welfare analysis of technological change. Skill biases may produce both winners and losers but there is a presumption of net gains in the sense that under SBTC the gains of the winners would be sufficient, in principle, to compensate the losers. There is no basis for this presumption in the case of power bias. A new technique can be profitable and may be adopted even if it is less efficient than existing techniques.¹⁰ This point can be illustrated by a simple variation on the analysis in Section Three. In Section Three we allowed for two types of labor, but price taking behavior in the product market and constant returns to labor eliminated all profits. We now abandon the assumption of constant returns to labor and, to simplify the presentation, assume homogeneous labor. Let the production function be

$$Y = A(0.5K^{-\alpha} + 0.5(eN)^{-\alpha})^{-1/\alpha} \quad (16)$$

where the non-labor input K is taken to be constant, and assume that workplace effort is determined as in Section Three. Using the specific functional forms in (11)-(13) - but without subscripts since there is only one kind of worker - the effects of changes in μ and the productivity parameter A can be calculated. An example is given in Table 3.¹¹ The rise in μ leads to an improvement in both wages and employment if A is unchanged. The interesting aspect of Table 3, however, is that when the rise in μ from 0.1 to 0.5 is combined with a very substantial loss of technical efficiency (a 25 percent fall in A from 10 to 7.5) profits π still increase while workers suffer a large reduction in wages and welfare. The negative effect on profits of lower technical efficiency is more than compensated for by the decrease in workers' power and the associated changes in effort and wages.¹²

Table 3: Effects of changes in monitoring

A	μ	e	w	u	h	x	π
10	0.1	0.45	4.91	0.21	3.93	4.12	1.40
10	0.5	0.63	5.53	0.19	4.42	4.62	2.29
7.5	0.5	0.60	4.12	0.21	3.29	3.47	1.54

Third, the source of the bias, may be important for an understanding of the diversity within the group of OECD countries. We have analysed the PBTC hypothesis using a traditional efficiency wage model as it applies to individual wage determination. This

¹⁰A Marx-inspired literature has analysed this issue, e.g. Marglin (1974) and Bowles (1985).

¹¹The table uses $\alpha = 1$. The other parameters are $\gamma = 5, r = 0.05, \delta = 0.2, K = 1$ and $b = 1$.

¹²The choice of μ is not necessarily a zero sum game, with any gains to firms coming at the expense of workers. In the Cobb-Douglas case in Table 1a, workers benefitted from a reduction in their workplace power and in this case too, a Cobb-Douglas specification of (16) may do the trick: assuming profit maximization and perfect competition in the product market, profits are a constant share of output, and it follows that if technological change (a shift in A and/or μ) generates an increase in profits then aggregate wages must also go up.

model, arguably, provides a good approximation of wage setting in the US, UK, and other liberal market economies (using the term in the sense employed by Hall and Soskice (2001)), but it may be less appropriate for countries in which wage bargains are more likely to be collective. Unions, moreover, influence working conditions as well as wages. Thus, there is evidence that the presence of strong unions reduces the impact of the cost of job loss on effort (Green and McIntosh, 1998), and among European countries there is a correlation between loss of union power and the rate of work intensification (Green and McIntosh, 2001). It is interesting to note, therefore, that there are pronounced differences with respect to both levels of and changes in wage inequality between the liberal market economies and economies in which collective bargaining over wages plays an important role

Wallerstein (1999) finds that most of the variance in inequality in 16 OECD countries between 1980 and 1992 is explained by differences in the degree of the centralization (with centralization increasing from individual to plant to industry to nation) of wage bargaining, together with the extent of collective bargaining coverage. However, most of the variation in Wallerstein's data is cross sectional. Only three of his countries show large changes in wage inequality over the period studied; in 1992 those three (the US, Canada, and the UK) had the first, second and fourth highest levels of wage inequality among the 16 studied. If we attribute changes in inequality to technological change, and assuming that the countries had access to the same technologies at the same time, then among the rich countries technological change raised wage overall inequality *only* where individual wage bargaining was the norm.

That much is true whether the link between technology and earnings is skill or power, but the implications are different. Under the SBTC hypothesis (and also the trade hypothesis, not considered here), the centrally bargained compression of wage differences generates unemployment and, in the longer run investment in human capital will eventually reduce inequality in the liberal economies, while the more centralized ones will suffer high unemployment until they accept a greater measure of inequality.¹³ On the other hand, if the PBTC hypothesis is true, the compression of wage differences may carry no such penalties. To see this, note that in the - admittedly extreme - case in which effort levels are set and controlled by unions there are no agency problems between firms and workers: from a single firm's perspective, effort is exogenously given. Having effort levels exogenously determined, moreover, does not block technological progress; it merely weeds out those changes of technique that are profitable only because of work intensification.

¹³It is beyond the scope of this paper to discuss the empirical evidence in any detail but the association between low earnings inequality and high unemployment is weak: Norway and Sweden, for instance, have not suffered high unemployment during the relevant period, the recovery during the 1990s from high unemployment in the 1980s was as strong in Denmark as in the UK, and the employment rate among low-skill men fell more in the US than in Germany between 1970 and 1990. We may note also that skill levels of unemployed Germans are high enough to cast doubt on the SBTC explanation for their lack of jobs (Freeman and Schettkat 2001) and that European countries with high unemployment had significant increases in high-skill as well as low-skill unemployment (Nickell and Bell 1996).

Overall then, PBTC suggests an institutional solution to what may otherwise be an ongoing state of high earnings inequality in the liberal market economies, and although any solution involving centralized wage bargaining might seem fanciful in the US and UK today, there is a case for the view that the power of unions in both countries has followed a long-wave pattern in the past (Fairris 1997; Kelly 1998).

In the SBTC case, a better provision of skills has been the standard suggestion for reducing income inequality. Since the standard efficiency wage model does not negate the link between changes in the relative labor supply and relative wages, it should also be possible to reverse a PBTC-induced rise in inequality through education and training if, as argued in Section Two, high-skill jobs tend to be associated with high power. Indeed, assuming that workers are always matched to jobs of their type, it is straightforward to show that in the model of Section Three, an increase in the relative supply of high-power workers will reduce inequality. The presence of ‘overeducation’, however, calls into question the efficacy of the education and training response to rising inequality. High-skill workers may fill low-skill jobs, and there is strong evidence that this kind of mismatch is widespread. The presence of overeducation can be explained within an efficiency-wage framework, and simple simulations of a model of this kind show that the effects of changes in the composition of the labor force can have very weak or even paradoxical effects on relative wages: an increase in the relative supply of high-skill workers forces more high-skill workers into low-skill jobs, this hurts the employment prospects of low-skill workers, and in extreme cases the skill premium may even increase (Skott 2006).¹⁴

5 Conclusion

The application of new technologies in the workplaces may change skill requirements but it also changes the relative power of different employees. Either sort of change might be distributed across jobs in a way that does not affect the aggregate earnings distribution, or alternatively might be distributed in a way that generates overall changes in the level of inequality.

The US and the UK along with some (but by no means all) other countries have experienced an increase in earnings inequality. This increase has been explained in terms of increased returns to skill, but the fact that more skilled employees are assigned to better paying jobs does not demonstrate that it is only the skill that is being compensated. The empirical evidence does not allow a clear test of the relative importance of power and skill biases for the movements in relative wages. Our reading of the evidence, however, suggests that the more important changes associated with new technology may relate to power rather than skill. ICTs have reduced the scope for consequential decision making by lower-paid employees, and increased that for higher-paid employees. Since the lower-paid

¹⁴The presence of overeducation also implies that relative unemployment rates may be insensitive to movements in relative wages arising from shifts in wage norms (Skott 2005).

employees tend to have lower levels of measured skill, this increased differential shows up empirically as an increased return to skill within organizations.

Our formal model in this paper is limited to changes in monitoring, which is just one avenue by which ICTs can affect the workplace power of employees. It deals only with individual effort choices and wage bargains, abstracting from any form of collective action. Within this limited territory, however, it demonstrates that changes in power relationships (the PBTC hypothesis) can explain the simultaneous occurrence of lower wages, higher unemployment and higher work effort for the lower skilled; changes in the demand for skills (SBTC) can explain the first two of these but is silent on the third.

References

- [1] Auerbach, Paul. *Competition*. Oxford: Blackwell, 1988.
- [2] Autor, David H., Frank Levy, and Richard J. Murnane. "The skill content of recent technological change: an empirical exploration". NBER Working paper 8377, 2001.
- [3] Autor, David H.; Lawrence F. Katz and Alan B. Krueger "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics*, 1998, 113(4), pp. 1169-1213.
- [4] Batt, Rosemary. "Explaining Wage Inequality in Telecommunications Services: Customer Segmentation, Human Resource Practices, and Union Decline." *Industrial and Labor Relations Review*, 2001, 54(2A), pp. 425-49.
- [5] Berman, Eli, John Bound, and Zvi Griliches. "Changes in the Demand for Skilled Labor within US Manufacturing: Evidence from the Annual Survey of Manufacturers." *Quarterly Journal of Economics*, 1994, 109 (2), pp. 367-397.
- [6] Berman, Eli, John Bound, and Stephen Machin. "Implications of Skill-Biased Technological Change: International Evidence". *Quarterly Journal of Economics* 1998, 113 (4), pp. 1245-1279.
- [7] Bowles, S. "The Production Process in a Competitive Economy: Walrasian, Neo-Hobbesian, and Marxian Models". *American Economic Review*, 1985, 75 (1), pp. 16-36.
- [8] Bowles, Samuel, and Herbert Gintis. *Schooling in Capitalist America: Educational Reform and the Contradictions of Economic Life*. New York: Basic Books, 1976.
- [9] Braverman, Harry. *Labor and Monopoly Capital*. New York: Monthly Review Press, 1974.
- [10] Bresnahan, Timothy F. "Computerisation and Wage Dispersion: An Analytical Re-interpretation." *Economic Journal*, 1999, 109(456), pp. F390-F415.

- [11] Bresnahan, Timothy F, Erik Brynjolfsson and Lorin M. Hitt "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." *Quarterly Journal of Economics*, 2002, 117(1), pp. 339-76.
- [12] Card, D., F. Kramarz and T. Lemieux "Changes in the Relative Structure of Wages and Employment: A Comparison of the United States, Canada and France". *Canadian Journal of Economics*, 1999, 32 (4), pp. 843-877.
- [13] Chandler, Alfred D. Jr. *Strategy and Structure: Chapters in the History of the American Industrial Enterprise*. Cambridge, Mass.: MIT Press, 1962.
- [14] Davis, Steve J and John Haltiwanger. "Wage Dispersion between and within Us Manufacturing Plants." *Brookings Papers on Economic Activity. Microeconomics.*, 1991, , pp. 115-200.
- [15] DiNardo, John E., and Jorn Steffen Pischke. "The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too?" *Quarterly Journal of Economics*, 1997, 112 (1):291-303.
- [16] DiNardo, John, Nicole M. Fortin, and Thomas Lemieux. "Labor Market Institutions and the Distribution of Wages, 1973-1992: A Semiparametric Approach". *Econometrica*, 1996, 64 (5):1001-1044.
- [17] Entorf, Horst and Francis Kramarz. "Does Unmeasured Ability Explain the Higher Wages of New Technology Workers?" *European Economic Review*, 1997, 41, pp. 1489-509.
- [18] Fairris, David. *Shopfloor Matters: Labor-Management Relations in Twentieth-Century American Manufacturing*. London: Routledge, 1997.
- [19] Forth, John and Neil Millward. "High-Involvement Management and Pay in Britain." *Industrial Relations*, 2004, 43(1), pp. 98-119.
- [20] Freeman, Richard and Ronald Schettkat. "Skill Compression, Wage Differentials, and Employment: Germany Vs the Us." *Oxford Economic Papers*, 2001, 3, pp. 582-604.
- [21] Gintis, Herbert and Tsuneo Ishikawa. "Wages, Work Intensity, and Unemployment." *Journal of the Japanese and International Economies*, 1987, 1, pp. 195-228.
- [22] Gottschalk, Peter, and Timothy M. Smeeding. "Cross-national comparisons of earnings and income inequality". *Journal of Economic Literature*, 1997, 35 (2):633-687.
- [23] Green, Francis. "It's Been a Hard Day's Night: The Concentration and Intensification of Work in Late Twentieth-Century Britain". *British Journal of Industrial Relations*, 2001, 39 (1), pp. 53-80.

- [24] Green, Francis. "Why Has Work Effort Become More Intense?" *Industrial Relations*, 2004, 43 (4), pp. 709-741.
- [25] Green, Francis, and Steven McIntosh. "The Intensification of Work in Europe." *Labour Economics* 2001, 8, no. 2 pp. 291-308.
- [26] Green, Francis, and Steven McIntosh. "Union Power, Cost of Job Loss and Workers' Effort." *Industrial and Labor Relations Review*, 1998 51, no. 3, pp. 363-83
- [27] Grimshaw, Damian, Huw Beynon, Jill Rubery and Kevin G. Ward "The Restructuring of Career Paths in Large Service Sector Organisations: 'Delaying', Upskilling and Polarisation." *Sociological Review*, 2002, 50(1), pp. 89-116.
- [28] Grimshaw, Damian, Kevin G. Ward, Jill Rubery and Huw Beynon. "Organisations and the Transformation of the Internal labor Market." *Work, Employment, Society*, 2001, 15(1), pp. 25-54.
- [29] Guy, Frederick. "High-Involvement Work Practices and Employee Bargaining Power". *Employee Relations*, 2003, 24 (5), pp. 453-469.
- [30] Hall, Peter A, and David Soskice, eds. *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*. Oxford: Oxford University Press, 2001.
- [31] Handel, Michael and Maury Gittleman. "Is There a Wage Payoff to Innovative Work Practices?" *Industrial Relations*, 2004, 43(1), pp. 67-97.
- [32] Handel, Michael J. "Skills Mismatch in the Labor Market." *Annual Review of Sociology*, 2003, 29, pp. 135-65.
- [33] Hunter, Larry W and John J. Lufkas. "Opening the Box: Information Technology, Work Practices, and Wages." *Industrial and Labor Relations Review*, 2003, 56(2), pp. 224-43.
- [34] Katzner, Donald W. and Peter Skott. "Economic Explanation, Ordinality and the Adequacy of Analytic Specification". *Journal of Economic Methodology*, 2004 (4), pp. 437-453.
- [35] Kelly, John. *Rethinking Industrial Relations: Mobilization, Collectivism and Long Waves*. London: Routledge, 1998.
- [36] Leamer, Edward E. "Wage Inequality from International Competition and Technological Change: Theory and Country Experience". *American Economic Review*, 1996, 86 (2), pp. 309-314.
- [37] Marglin, Stephen A. "What Do Bosses Do?" *Review of Radical Political Economics*, 1974, 6 (2), pp. 60-112.

- [38] Miozzo, Marcela, and Matias Ramirez. "Services innovation and the transformation of work: the case of UK telecommunications". *New Technology, Work and Employment*, 2003, 18 (1), pp. 62-79.
- [39] Nickell, S. and B. Bell. "Changes in the distribution of wages and unemployment in OECD countries". *American Economic Review, Papers and Proceedings*, 1996, 86 (2), pp. 302-308.
- [40] Piva, Mariacristina, Enrico Santarelli, and Marco Vivarelli. "The skill bias effect of technological and organisational change: evidence and policy implications". *Research Policy*, 2005.
- [41] Sewell, Graham. "The Discipline of Teams: The Control of Team-Based Industrial Work Through Electronic and Peer Surveillance". *Administrative Science Quarterly*, 1998, 43 (2).
- [42] Skott, Peter. "Fairness as a Source of Hysteresis in Employment and Relative Wages". *Journal of Economic Behavior and Organization*, 2005, 57 (3), 305-331.
- [43] ———. "Wage Inequality and Overeducation in a Model with Efficiency Wages". Department of Economics Working Paper 2005-06, University of Massachusetts. Forthcoming in *Canadian Journal of Economics*, February, 2006.
- [44] Skott, Peter and Paul Auerbach. "Wage Inequality and Skill Asymmetries". In M. Setterfield (ed.) *Interactions in Analytical Political Economy: Theory, Policy and Applications*, M.E. Sharpe, 2005, pp. 27-54.
- [45] Wallerstein, Michael. "Wage-setting institutions and pay inequality in advanced industrial societies". *American Journal of Political Science*, 1999, 43 (3), pp. 649-680.

6 Appendices

6.1 Appendix A: Effort and technical change

Let ε_L and ε_H be verbal descriptions of work activities and assume that, for the worker, different work activities are associated with different flows of utility.¹⁵ Let e_L and e_H be orderings defined by

$$e'_i = f_i(\varepsilon'_i) \geq f_i(\varepsilon_i) = e_i \text{ if and only if } u(c, \varepsilon'_i) \leq u(c, \varepsilon_i)$$

and assume that this ordering is independent of the level of consumption. Define the set $\Omega_i(x) = \{\varepsilon_i \mid f_i(\varepsilon_i) \leq x\}$.

¹⁵See Katzner and Skott (2004) for an analysis of methodological problems surrounding the use of ordinal variables like "effort".

Let the production function before technical change be given by

$$Y = G(\varepsilon_L, N_L, \varepsilon_H, N_H)$$

and assume that

$$\max_{\varepsilon_i \in \Omega_i(e_i)} G(\varepsilon_L, N_L, \varepsilon_H, N_H) = F(e_L N_L, e_H N_H)$$

Technical change is unbiased if, after the change, the new production function $\tilde{G}(\varepsilon_L, N_L, \varepsilon_H, N_H)$ satisfies

$$\max_{\varepsilon_i \in \Omega_i(e_i)} \tilde{G}(\varepsilon_L, N_L, \varepsilon_H, N_H) = AF(e_L N_L, e_H N_H)$$

6.2 Appendix B: Intertemporal optimization

Consider an infinitely lived agent with instantaneous utility function

$$u(c, e) = c - v(e)$$

Assume that the interest rate r is equal to the discount rate. The time profile of consumption is then a matter of indifference to the agent, and we may assume that consumption matches current income. If U denotes the value function of an unemployed worker, a worker who is currently employed at a wage w faces an optimization problem that can be written

$$\max E \int_0^T (w - v(e)) \exp(-rt) dt + \exp(-rT) U$$

where the stochastic variable T denotes the time that the worker loses the job. Assuming a constant hazard rate, T is exponentially distributed. If we define $h = rU$, the objective function can be rewritten

$$\begin{aligned} E \int_0^T (w - v(e)) \exp(-rt) dt + \exp(-rT) U &= E \int_0^T (w - v(e) - h) \exp(-rt) dt + U \\ &= E \left(\frac{w - v(e) - h}{r} (1 - \exp(-rT)) \right) + U \\ &= (w - v(e) - h)p + U \end{aligned}$$

where $p = E(1 - \exp(-rT))/r = (1 - \frac{\delta}{r+\delta})/r = \frac{1}{r+\delta}$ is an increasing function of the rate of separations δ . Effort affects the firing probability and thus the rate of separations, so the worker's first order condition can be written

$$-v'(e)p(e) + (w - v(e) - h)p'(e) = 0$$

The value function for an unemployed worker will depend on the average level of wages, the rate of unemployment benefits and the hiring rate. With a constant rate of unemployment, the hiring rate, q , is proportional to the average rate of separations rate

$$q = \bar{\delta} \frac{L}{N - L} = \bar{\delta} \frac{1 - u}{u}$$

where u is the unemployment rate and $\bar{\delta}$ is the average rate of separations. The risk of job loss gives an incentive for workers to provide effort. But an increased average firing rate does not help the firm unless it raises effort (on the contrary, high labor turnover is usually costly). Since effort is determined by the semi-elasticity p'/p (see the first order condition) it follows that the average firing rate in the economy need not be related to the average level of effort and, secondly, that an improved ability to detect individual effort - a rise in p'/p - may change the average (standard) effort but need not be associated with any changes in the firing rate for workers that meet this changed standard. Thus, it is reasonable to assume that $\bar{\delta}$ is constant. But since average effort is itself determined by \bar{w}, b and u , whether or not $\bar{\delta}$ depends on \bar{e} , we have

$$h = h(\bar{w}, b, u)$$

In equilibrium, $w = \bar{w}$ and in order to find the value of h we note that

$$V - U = (w - h - v(e))p \tag{B1}$$

$$U - V = (b - rV)s = \left\{ b - r[(w - h - v(e))p + \frac{h}{r}] \right\} s \tag{B2}$$

where $s = E\left(\frac{1 - \exp(-rT_u)}{r}\right)$ and the stochastic variable T_u denotes the remaining length of the spell of unemployment of a currently unemployed worker. With a constant rate of separations, random hiring and constant unemployment, the stochastic variable T_u follows an exponential distribution with expected value $ET_u = \frac{u}{1-u}ET$ where $ET = 1/\bar{\delta}$ is the average expected remaining duration of employment for an employed worker. Using (B1)-(B2) and the expressions for p and s ($p = 1/(r + \delta)$; $s = 1/(r + \delta(1 - u)/u)$), it follows that

$$\begin{aligned} h &= (w - v(e)) \frac{p - rps}{p + s - rps} + b \frac{s}{p + s - rps} \\ &= (w - v(e)) \frac{\delta(1 - u)}{ru + \delta} + b \frac{(r + \delta)u}{ru + \delta} \end{aligned}$$

Thus, the fallback position is a weighted average of the utility flows while employed and unemployed with the weights depending on the rate of unemployment.

6.3 Appendix C: Derivation of (11)-(12)

Using (9)-(10) and omitting the superscripts, the first order condition (2) can be written

$$\gamma e^{\gamma-1} = (w - e^\gamma - h) \frac{\mu}{e}$$

or

$$e = \left[\frac{\mu}{\mu + \gamma} (w - h) \right]^{1/\gamma} \quad (\text{C1})$$

It follows that

$$e_w = \frac{1}{\gamma} \frac{\left[\frac{\mu}{\mu + \gamma} (w - h) \right]^{1/\gamma}}{w - h}$$

The firm's first order condition (5) yields

$$\frac{1}{\gamma} \frac{w}{w - h} = 1$$

or

$$w = \frac{\gamma}{\gamma - 1} h \quad (\text{C2})$$

6.4 Appendix D: Effects of an increase in μ_L when $\rho = -1$.

When $\rho = -1$, the production function is

$$Y = 0.5A(e_L N_L + e_H N_H)$$

and at an interior solution with $0 < u_L < 1$ we have

$$w_L = 0.5Ae_L \quad (\text{D1})$$

Using (D1), (11)-(12) and (C2), it follows that

$$\begin{aligned} \frac{d \log w_L}{d \log \mu_L} &= \frac{d \log e_L}{d \log \mu_L} \\ \frac{d \log e_L}{d \log \mu_L} &= \frac{1}{\gamma} \left(\frac{d \log \left(\frac{\mu_L}{\mu_L + \gamma} \right)}{d \log \mu_L} + \frac{d \log w_L}{d \log \mu_L} \right) \end{aligned}$$

Hence,

$$\frac{d \log w_L}{d \log \mu_L} = \frac{d \log e_L}{d \log \mu_L} = \frac{1}{\gamma - 1} \frac{d \log \left(\frac{\mu_L}{\mu_L + \gamma} \right)}{d \log \mu_L} > 0$$

To show that N_L must also rise, we note that - combining(11)-(13) - h_L can be written

$$h_L = \frac{bf(u_L)}{\frac{-\gamma}{(\gamma-1)(\mu_L+\gamma)} + f(u_L) \left[1 + \frac{\gamma}{(\gamma-1)(\mu_L+\gamma)} \right]}$$

where $f(u_L) = \frac{(r+\delta)u_L}{ru_L+\delta}$ and $f' > 0$. The value of h_L is decreasing in both μ_L and u_L . Since h_L is proportional to w_L and since w_L increases following a rise in μ_L , it follows that u_L must decrease.