Power-Biased Technological Change and the Rise in Earnings Inequality

Frederick Guy* and Peter Skott†

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Abstract

New information and communication technologies (ICTs) affect organizations and jobs, and as a result the power that different employees exercise at work may change: the power of workers decreases if the ability of firms to monitor their 'effort' improves; the scope for decision making by workers, on the other hand, may also increase, thus increasing worker power. This paper shows that technical change may have been 'power-biased'. New ICTs allow firms (managers) to monitor low-skill workers more closely but make it harder to monitor high-skill workers. We set up an efficiency wage model to examine the effects of 'power-biased technical change' (PBTC). It is shown that lower-skilled workers may experience a decline in wages accompanied by an increase in both effort and unemployment.

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

*School of Management and Organizational Psychology, Birkbeck College, Malet St, London WC1E 7HX, UK; f.guy@bbk.ac.uk

†Department of Economics, University of Massachusetts, Amherst, MA 01003, USA; pskott@econs.umass.edu.

1 Introduction

New technologies, and in particular information and communications technologies (ICTs), are widely believed to have contributed to increased earnings inequality. The most widely accepted explanation for the way in which this contribution works is the skill-biased technological change (SBTC) hypothesis. This hypothesis holds that the adoption of the current generation of ICTs increases the demand for new skills or high skills, and reduces the demand for old skills or low skills; if demand for skills due to SBTC outstrips changes in the supply of skills, the relative wages of higher-skilled workers are bid up, and those of lower-skilled workers fall. The SBTC hypothesis explains why the rise in wage inequality may be associated with a fall in the employment of less skilled workers.

The SBTC explanation is consistent with the human capital theory of wage determination, and thus fits neatly into the general competitive model of the economy. It also has the reassuring implication that the increase in earnings inequality can be reversed over time through education and training alone. New ICTs, however, affect the jobs people do in ways other than changing skill requirements. ICTs allow organizations to become flexible, flat, decentralized, customer-oriented, and as a consequence to give employees increased discretion. At the same time, however, ICTs allow managers to monitor the actions of employees more closely, and also to prescribe the desired actions of employees more precisely, with the effect of constraining the ability of employees to make consequential choices for the organization. Discretion and its inverse, constraint, develop hand in hand, and it can be difficult, even *ex post,* to sort out what is the net change in discretion for any particular employee.

Discretion matters to the extent that choices have consequences. We define an employee's power, in relation to the employer, as the employee's ability to affect outcomes for the employer: this ability is a product of discretion (scope for choice), and the differences such choices make. Power is correlated with skill – other things equal, 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. With incomplete contracting for employee actions and self-interested actors, the degree of power will affect the employee's level of earnings. We illustrate this below with an efficiency wage model, but on this central point any sort of agency model would do.

For the purposes of understanding changes in earnings inequality, is power important, compared with skill? We review the literature on skill, and note a number of empirical anomalies confronting the SBTC hypothesis, which can be better explained in terms of discretion. We develop an efficiency wage model which shows that reduced power can lead simultaneously to increased effort, reduced earnings *and* reduced employment levels for less skilled workers, independent of the market for human capital. Thus, power-biased technological change (PBTC) may be a plausible alternate hypothesis to explain the trends in relative employment and earnings.

The remainder of this paper is organized as follows. In section 2, we elaborate on the ways in which new ICTs and organizational transformation may affect the power of employees. In section 3, we review evidence on changes in the distribution of earnings, and the connection between these changes and changes in ICTs, skills and organization structure. We also identify certain issues which are problematic for both the SBTC and the PBTC hypotheses. In section 4, we develop an efficiency wage model which shows that PBTC can explain some of the anomalies which afflict the SBTC story. Section 5 concludes.

2 ICTs, Organizational Transformation, and Power

The SBTC hypothesis explains changes in the distribution of earnings in terms of technologically-driven changes in the demand for human capital. If new technology (as embedded in new physical capital) is complementary with skill, and investment in physical capital outpaces investment in human capital, the earnings of those with skills appropriate for the new physical capital will rise relative to those without such skills.

Complicating the SBTC story is that, when we talk about the introduction of ICTs, we are not talking about so many electronic typewriters replacing manual ones on old desks. Use of the new technologies often entails, or is associated with, significant changes in the way organizations are managed and individual jobs are structured. These changes are not easy to characterize, because they take a number of different forms, and also because the rhetoric of organizational transformation is not always a good guide to reality. Consider, however, the following elements:

(1) ICTs enhance the manager's ability to monitor workers. Assume for the moment that although ICTs improve, the task the employee is asked to complete does not change. Improved monitoring will narrow the scope of action open to a worker in two ways. One is that the manager has a better idea of what the worker actually does. The other is that the manager has better information about the environment in which the worker works, the options she faces and the effect that different actions the worker might take would have on completion of the task. In other words, the manager has improved knowledge of both the worker's actions, and the state of nature in which those actions take place. For

instance, prior to the 1980s a truck driver's employer usually had only a vague idea of where he and the truck were. Now the location of the truck, and even the behavior of its engine, are often tracked by satellite. The driver's task may change little, 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.

(2) Contrary to the assumption made in (1), however, tasks typically do change as part of the organizational transformations that go together with the introduction of new ICTs. For instance, 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 assigning individual accountability when actions are taken by teams.

(3) Changes also occur 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' (Alfred D. Jr. Chandler, 1962).

Let us define an employee's power as the extent of her discretionary ability to affect the employer's welfare. That is to say, power is the product of choices an employee can make, and the potential consequences (for the employer) of those choices. Standard efficiency wage models tell us that wages are positively related to the marginal productivity of an employee's effort, and negatively related to the intensity of monitoring (George A. Akerlof and Janet L. Yellen, 1986, Herbert Gintis and Tsuneo Ishikawa, 1987). In the language used here, that means that, ceteris paribus, employees with more power are paid more. Employees may be workers or managers. From the examples just given, we can see that an ICT-driven restructuring has the potential to either increase or decrease the power of both workers and managers. Because of the obvious ways in which ICT-driven organizational restructuring can affect power relations, it would be very surprising if changes in power relations were not an element in the changes to individual wage levels. Yet this doesn't tell us anything about what sort of pattern to expect: would changes in power relations expand, or compress, differentials between managers and workers? Would they increase, or decrease, the overall variance of earnings?

It is important to know to what extent the relationship between technology and the distribution of earnings is mediated by skill, and to what extent by power. To the extent that earnings inequality has increased because of SBTC, inequality can be reduced by policies which improve the skills of those at the lower end of the distribution.[1] In this vein, Goldin and Katz (1998) argue that SBTC in the early 20th century was not followed by a rise in earnings inequality in the US because of the rapid spread of free secondary education. But what if inequality has risen, at least in part, because of a changed distribution of power within organizations? In this case, any effort to reverse the rise would require measures which spoke to the power of different groups of employees, individually or collectively. The nature of such measures is beyond the scope of this paper, except to note that simple human capital accumulation may not fill the bill.

3 Reading the Evidence

Due to the hegemony of SBTC, we begin by reviewing the evidence adduced in its favor. We find that in many cases there are significant gaps in the evidence for the hypothesized causal chain, and that for much of the evidence, SBTC and PBTC are observationally equivalent. We identify some important anomalies and lacunae in the SBTC story, which might be explained by PBTC.

3.1 What is meant by 'skill'?

Just what sort of skill is involved in the hypothesized skill bias? Some studies view the problem as one of adequate literacy and numeracy, others technology-specific skills, and still others packages of social or teamwork skills.

One circumstance in which changed skill requirements can translate into increased earnings inequality is that the new skills are either very expensive to acquire, or in short supply. Handel (2003) shows that, for the US, there is not convincing evidence of any shortage of literacy, numeracy, or general technology-specific (e.g., computer) skills, while employers do report difficulties finding people with the right social and teamwork skills.

[1] However, as Sattinger (1979) shows, the distribution of earnings will be affected by a technological change which changes the distribution, across workers, of capital used on the job. The variance of capital-labor ratios across industries rose in the US after 1978, and earnings are positively correlated with K/L (Caselli 1999).

Moreover, training in the skills required for use both with new technologies and new forms of work organization is often provided by employers (see H Frederick Jr Gale et al., 2002, for evidence on US manufacturing, Francis Green et al., 2001, for evidence from a broad sample of UK employees).

The emphasis which Gale et al. and Green et al. place on social and teamwork skills reflects a growing sense among researchers in this area that the connection between new technology and changes in the demand for skill is often mediated by technologically-facilitated changes in the organization of work. Bresnahan (1999) argues SBTC should be understood as a consequence of organizational restructuring creating demand for a scarce bundle of social skills, such as the ability to work well in teams. We argued above that teamwork has implications for the power of team members. We should add here that "teamwork" designates both a set of skills and a set of behaviors.

3.2 The growth of between-establishment earnings dispersion.

Davis and Haltiwanger (1991) studied US manufacturing plants from 1963-86. They find a rise in earnings dispersion (inequality not accounted for by the regression model) for operatives after 1975, and both the dispersion and its rise are much greater between plants than within. Davis and Haltiwanger argue that this is evidence for skill-biased technological change, on the grounds that the large increases both in between-plant dispersion and in the plant size earnings effect were best explained by increased sorting of workers by unobserved skill. Their result depends on an audacious knitting together of plant level data with individual observations from the Current Population Survey, and not a direct measurement of either the skill endowments of the employees at the plants, or the skill requirements for their jobs. It has nonetheless become widely accepted that increased between-plant (or between-firm) earnings dispersion results from sorting by skill. Acemoglu (1999), and Kremer and Maskin (1997), among others, have produced theoretical models of this stylized fact. Yet when O'Shaughnessy et al (2001) examine a somewhat later (1986-92) rise in earnings dispersion for 50,000 managers in 39 US firms, their extremely fine controls for skill requirements do a good job of capturing within-firm earnings variation (i.e., within-firm earnings inequality rose, and much of this rise is captured as increased returns to skill), but not the rise in between-firm variation during this period.

One explanation for the rise in unexplained differences in earnings between plants or firms is found in the uneven adoption of new forms of work organization – forms which variously are labeled "high-commitment", "high-performance" or "high-involvement" work practices (HIWPs). HIWPs have often been found to be associated with higher wages. Forth and Millward (2004), for instance, find this for a broad sample of UK employers.

Handel and Gittleman (2004), in a study which parallels Forth and Millward for the US, maintain that they have found "little evidence that [HIWPs] are associated with higher wages"; however, they report substantively, and sometimes statistically, significant estimates of higher wages associated with some HIWPs, using a method in which errors in variables are likely to be biasing these estimates to zero. Hunter and Lafkas (2003), in a study of US banks, find that HIWPs are associated with higher wages, and that when new technology is used to automate routine practices it is associated with higher wages only if HIWPs are also present.

These studies find positive associations between particular HIWPs and wages, after controlling for human capital as well as the data allow. We are left with the question of whether the HIWP wage premium is due to unobserved skill, or to differences in the way the wage bargain works in HIWP workplaces. We have no conclusive evidence but the study by O'Shaughnessy et al. supports the latter explanation.

3.3 What are the relevant information technologies?

One way of motivating the SBTC hypothesis is that the introduction of new technologies leaves skills in short supply; the other side of this story is that unskilled workers (or, workers with a now-obsolete skill set) are relatively plentiful. The idea here is that the lower paid are lower paid because their skills, such as they are, are suited to yesterday's technology. This is because a particular cluster of ICTs constitute a new general purpose technology (GPT) which, within the space of a few decades, has become pervasive, making old technologies and skills quickly obsolete (Claudia Goldin and Lawrence F. Katz, 1998). At other times (in the 1950s and 1960s, say), incremental technological change might still have had a skill bias, but lacked the disruptive character of a new GPT, and so the supply of skills was able to keep up.

A problem with measuring the effects of a GPT is precisely that it is general purpose: microchips and bar code scanners and data networks are all around us, in many different forms. How do we isolate them and measure them in order to estimate the effect they have on jobs or wages? Many studies in the SBTC literature use computers as a measure of ICT (see, for instance, David H. Autor et al., 1998, Timothy F Bresnahan et al., 2002, Francis Green et al., 2000). The trouble with this is that computers are the flexible, multi-function, multi-skill end of ICT; also, when equipped as they often are with web connections, e-mail and games, they make monitoring of the employees using them more rather than less difficult. Compare this with just two other widespread workplace applications of ICT: the retail barcode scanner monitors the pace of work and also makes "under-rings" (undercharging, perhaps accidentally or perhaps for the benefit of a friend or relative) nearly impossible; satellite-linked systems which track both the location and the engine performance of a truck make a previously autonomous driver's job into one which is closely monitored. Both cases involve advanced ICTs and, indeed, computers, but both categories of worker would answer "no" to the question "do you use a computer at work?" And both are cases where the relative earnings of the workers in question have fallen steadily following the adoption of the new technologies.

Studies which do include measures of different kinds of technology tend not to find such a simple positive relationship between technology and earnings. For instance, Doms et al. (1997) find, in US manufacturing, that technology upgrading tends to happen in plants which already have more skilled and better paid workers, but not that the technology leads to higher skills or pay. Entorf and Kramarz (1997), using French panel data for individual workers in a broad sample of firms, find that workers using new technologies are paid more only if their jobs "leave large autonomy". Tellingly, though the technology in both cases is new, when it involves "large autonomy", Entorf and Kramarz call it "modern". This label reinforces the preconception that what is modern is new technology, empowered employees and high wages; yet Entorf and Kramarz's own findings also show us new technology paired with dis-empowered employees on lower wages.

That the low-wage tail of the earnings distribution may not represent yesterday's technology but the low-wage face of today's, finds support also in the workplace studies of Batt (2001) in US telecommunications, Grimshaw et al. (2002, 2001) in UK retailing, banking and pharmaceuticals, Hunter and Lafkas (2003) in US banking, and Taylor et al. (2002) in UK phone centers, among others.

3.4 Employment, Intensification, and Discretion

There are three further areas in which evidence may help us weigh the merits of the SBTC and PBTC hypotheses. These have to do with the relationship between wages and unemployment for low-skilled workers, the intensification of work, and changes in discretion on the job.

A collapse in demand for low-skilled workers is taken to be a vital piece of evidence for SBTC xxxx. Persistent unemployment in some European economies, in particular, is taken as evidence of an institutional refusal to allow the lower tail of wages to fall far enough to make workers with obsolete skills employable. On the other hand, Freeman and Schettkat (2001) find that unemployed Germans have skills similar to those of employed Germans, and more like average American workers than like low-skilled American workers. While this result takes some force out of the demand collapse story, the latter remains the predominant interpretation.

In Europe, work effort has become more intense in recent years (Francis Green, 2004). Green finds that in the UK, rising work intensity (employees saying that how hard people work has "gone up a lot" in their workplace) is associated with use of new technologies, high-commitment work practices, falling union power, and use of temporary or contract workers. Why should work in the new workplace be more intense?

The SBTC hypothesis treats the employment relationship as a straightforward market exchange, without problems of contract enforcement or other ex post questions of choice by employees. It offers no explanations for changes in the level of work intensity. If we take power into account, however, then intensity of work effort becomes a variable in the model.

An employee's power, as we define it here, comes from both the ability to make choices (discretion), and the potential effect of those choices on the employer. We have no way of measuring potential effect, but we do have some data on discretion.

In the UK Skills Survey, employees report a marked decline in task discretion between 1992 and 2001 (Francis Green, 2002). On the other hand, most of the US personnel executives surveyed by Bresnahan et al. (2002) in 1995-96 believe that use of computers increases autonomy (though they also believe, by the same margin, that use of computers increases monitoring). There are three ways of explaining the difference between the UK and US results. One is that Bresnahan et al. ask about computer use, not about jobs generally. Another is that personnel managers may have a different opinion on this than workers; in particular, to say that computers increase both autonomy and monitoring suggests that personnel managers are referring to an increase in formal autonomy (decisions managers intend workers to make), while monitoring restricts informal autonomy (slack in the system, which may not be acknowledged by the managers). A third is that there has historically been more task discretion in the UK, where the craft tradition remained relatively strong, Taylorism and bureaucracy relatively weak: thus, adoption of similar HIWPs could reduce task discretion in the UK in a way that it does not in the US. All we can say now is that there is clear evidence for reduced discretion in the UK, and that the situation in the US is unclear.

3.5 Summary

The evidence on the relationship between technology and rising earnings inequality does not point conclusively to skill bias. The evidence for skill shortages is weak; the large rise in between-establishment, -firm and –industry earnings dispersion is 'explained' by skill only if we assume that unobserved skill differences are responsible for the residual; use of ICTs has often been measured in ways which capture only the more empowering

ICTs (such as PCs); some of the proxies for skill, such as participation in teams, have clear power implications as well. Moreover, the SBTC model cannot explain why new forms of work organization and new technology would be associated with higher effort as well as changes in the distribution of earnings, and it is silent on the effect of changes in monitoring. On the other hand, a power-bias explanation would have to deal with the apparent fact that reduced relative earnings for low-skilled workers have not led to reduced relative unemployment for these workers. We address this question in the next section.

4 A formal model of power-biased but skill-neutral technical change

To keep the analysis simple we consider an economy with two types of workers, high and low skill, and assume that there is no heterogeneity among workers of a given type. 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, $i = H, L$; changes in the parameter A represent technical change.[2]

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. Most 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). Our concern in this paper, however, is with the effect of changes in the ability of firms to monitor effort. In order to focus on this aspect of the problem we

- assume that technical change is skill-neutral in the sense that while A may change, the $F-$function remains unchanged. This definition of Hicks-neutrality when effort is endogenous is discussed further in Appendix A. We

- consider power-biased technical change that leaves the monitoring conditions for high-skill workers unchanged but increase the ability of firms to monitor low-skill workers. Similar results for relative wages and relative employment rates could be

[2] We assume that employed workers always hold jobs that match their skills. A significant amount of evidence suggests that this assumption may be misleading. Skott (2005, 2005a) and Auerbach and Skott (2005) analyse alternative models in which unemployed high-skill workers may accept low-skill jobs.

obtained if changes in technology also made it more difficult to monitor high-skill workers. To simplify the exposition, finally, we

- assume that the wage and employment of high-skill workers are unaffected by the change in technique. High-skill wages and employment are endogenous variables, of course, but constant values of these variables will be generated if the change in the power of low-skill workers is accompanied by an appropriate skill-neutral shift (a change in A). This implicit assumption concerning the combination of skill-neutral and power-biased technical change is harmless, we conjecture, given our focus on changes in *relative* wages and *relative* employment.

Turning to the formal specification of the model, we first consider workers' choice of a level of effort. 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,

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

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).

The function $v^i(e_i)$ 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 $v^{i\prime} > 0, p^{i\prime} > 0$. The function $h^i(\bar{w}_i, b, u_i)$ represents the fallback position, that is, the expected utility in case of job loss. Using standard assumptions,

$$h^i_{\bar{w}} > 0, h^i_b > 0, h^i_u < 0$$

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

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

and we may write the solution to the problem as

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

The sign of the partial f^i_w 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 $f^i_{\bar{w}} < 0, f^i_b < 0, f^i_u > 0$.

Now introduce the effect of technical change on firms' ability to monitor effort. We consider a technical change that leaves the monitoring conditions for high-skill workers unchanged but enhances the monitoring of low-skill workers. This change may be represented by a shift in the p^L-function. Thus, let

$$\frac{p^{L\prime}}{p^L} = \lambda(e_L, \mu) \tag{4}$$

where the parameter μ 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 greater detail in appendix B, firms may keep the average firing rate constant.

Totally differentiating the first order condition, (2) we get

$$e_{L\mu} = \frac{\partial e_L}{\partial \mu} = -\frac{\phi_\mu}{\phi_e} > 0$$

where $\phi = -p^L v^{L\prime} + (w_i - v^L - h^L)p^{L\prime} = p^L[-v^{L\prime} + (w_i - v^L - h^L)\lambda]$. Using the first order condition, we have $\phi_\mu = p^L(w_i - v^L - h^L)\lambda_\mu + p^L_\mu[-v^{L\prime} + (w_i - v^L - h^L)\lambda] = p^L(w_i - v^L - h^L)\lambda_\mu > 0$, and the sign of $e_{L\mu}$ now follows from the second-order condition which implies that ϕ_e 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

$$\frac{e_{Lw} w_L}{e_L} = 1 \tag{5}$$

Using (3)-(5), the solutions for wage and effort can be expressed[3]

$$\begin{aligned} w_L &= w_L(\bar{w}_L, u_L; \mu) \\ e_L &= e_L(\bar{w}_L, u_L; \mu) \end{aligned}$$

In equilibrium, $w_L = \bar{w}_L$ and

$$w_L = w_L(u_L; \mu) \tag{6}$$
$$e_L = e_L(u_L; \mu) \tag{7}$$

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

Analogous equations can be derived for high-skill workers. The only difference is that by assumption the ability to monitor these workers is unchanged, and the monitoring parameter μ can therefore be omitted:

$$\begin{aligned} w_H &= w_H(u_H) && (8) \\ e_H &= e_H(u_H) && (9) \end{aligned}$$

Firms' first order conditions with respect to employment yield

$$\begin{aligned} w_H &= e_H A F_H(e_L N_L, e_H N_H) && (10) \\ w_L &= e_L A F_L(e_L N_L, e_H N_H) && (11) \end{aligned}$$

Combining (6)-(10) and using the definitional relations between unemployment u_i and employment N_i, equilibrium solutions for the endogenous variables can be found as functions of the two parameters A and μ that describe the technology:

$$\begin{aligned} N_H &= N_H(A,\mu), w_H = w_H(N_H) = w_H(A,\mu), e_H = e_H(N_H) = e_H(A,\mu) \\ N_L &= N_L(A,\mu), w_L = w_L(N_L,\mu) = w_L(A,\mu), e_L = e_L(N_L,\mu) = e_L(A,\mu) \end{aligned}$$

The effects on N_H of a change in μ, finally, can be offset by an appropriate change in A : locally our assumption that $N_H(A,\mu)$ remain constant defines A as an implicit function of μ, $A = A(\mu)$ (assuming that $\partial N_H/\partial A \neq 0$).

Without functional forms it is difficult to derive precise conclusions concerning the effects of a decline in the power of low-skill workers (an increase in μ). Thus, as an example, let

$$\begin{aligned} \frac{p'}{p} &= \lambda(e,\mu) = \frac{\mu}{e} && (12) \\ v(e) &= e^{\gamma}, \gamma > 1 && (13) \\ h(\bar{w},u,b) &= ub + (1-u)(\bar{w} - \bar{e}^{\gamma}) && (14) \end{aligned}$$

By assumption the wage, employment and effort of high-skill workers remains unchanged. Only the equations for low-skill workers need be specified and to simplify notation we have therefore omitted the sub- and superscript L in equations (12)-(14).

The specification of the semi-elasticity of the $p-$function in (12) can be interpreted as a log-linear approximation of the $p-$function around the equilibrium solution for e.[4]

[4] Integration of (12) implies that

$$p = Ke^{\mu}$$

Equations (13)-(14) are quite standard. The parameter restriction $\gamma > 1$ in equation (13) implies that given the chosen scale of effort, the disutility of effort is strictly convex.[5] This convexity assumption ensures that the firm's unit cost of effort does not decrease monotonically as wages increase (and that, therefore, an equilibrium solution for w exists). Equation (14) gives the fallback position as a weighted average of the utility in unemployment and in another job. The latter utility is given by the difference between wage in other firms ($\bar{w}$) and the disutillity of the associated optimal effort ($\bar{e}^{\gamma}$ where $\bar{e}$ is determined by setting $w_i = \bar{w}_i$ in equation (3)).

The specification (12)-(14) implies that (6)-(7) take the following form (see Appendix C)

$$e = \left[\frac{\mu}{\mu+\gamma}\frac{1}{\gamma-1}h\right]^{1/\gamma} \tag{15}$$

$$w = \frac{\gamma}{\gamma-1}h \tag{16}$$

where

$$h = \frac{b(1-u)}{1-(1-u)(\frac{\gamma}{\gamma-1}-\frac{\mu}{(\gamma-1)(\mu+\gamma)})} \tag{17}$$

Turning now to determination of labor demand and assuming a CES production function, the relative wage must satisfy

$$\frac{w_H}{w_L} = B\left(\frac{N_L}{N_H}\right)^{\rho+1}\left(\frac{e_L}{e_H}\right)^{\rho} \tag{18}$$

where $\sigma = 1/(1+\rho)$ is the elasticity of substitution. By assumption, the changes in μ and A leave w_H and u_H unchanged, and it follows that e_H is then also unchanged. Hence, equation (18) implies that

$$w_L = CN_L^{-(\rho+1)}e_L^{-\rho} \tag{19}$$

where the constant C is given by $C = Bw_H N_H^{\rho+1}e_H^{\rho}$. Normalizing the supply of low-skill labor at unity (so that $u_L = 1 - N_L$) and omitting the subscripts, equation (19) can be written

$$w = C(1-u)^{-(\rho+1)}e^{-\rho} \tag{20}$$

where K is an arbitrary constant. The intertemporal interpretation in Appendix B of workers' maximisation problem implies that p is bounded, unlike the above expression. It follows that equation (12) must be seen as an approximation if the intertemporal interpretation of the maximisation problem is adopted.

[5] Effort 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 effects of a rise in μ can be derived using (15)-(17) and (20).

Not surprisingly, the elasticity of substitution plays a critical role. It can be shown that whether or not the two types of labor are complements, an increase in μ must lead to a decline in w_L or N_L (see Appendix D). In the case of complementarity, however, improved monitoring may hurt low-skill workers in all three dimensions: workers increase effort but may suffer a decline in both wages and employment. This outcome can be ruled out when the two types of labor are substitutes since either wage or employment must then increase if effort goes up (see Appendix D).

The numerical examples in Table 1 illustrate these possibilities. The examples consider different values of the parameters ρ, γ and μ from (what we consider) their plausible ranges.[6] Tables 1a-1c, which assume complementarity ($\rho > 0$), show the deterioration in the conditions of low-skilled workers along all three dimensions: effort and unemployment increase and wages fall as μ increases. The wage and employment effects are particularly strong in Table 1b which assumes a low elasticity of substitution ($\rho = 4$ or $\sigma = 1/(1+\rho) = 0.2$). In Table 1d the production function is Cobb-Douglas ($\rho = 0$), and the rise in μ produces a slight decline in unemployment along with a slight fall in wages. In each of the four scenarios, the parameter C is chosen to give employment rates in an empirically reasonable range of about 75-80 percent.

[6] Most studies (e.g. Card et al. 1999) suggest a relatively low elasticity of substitution between high and low skill workers (that is, $\rho > 0$).

Turning to μ, 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.

The parameter γ, finally, must be greater then one, and the qualitative results appear to be insensitive to the precise value.

Table 1: Effects of PBTC on the effort, wage and unemployment of low-skill workers

1a: $\gamma = 10, \rho = 1; C = 0.6$

μ	e	w	u
0.1	0.53	1.84	0.22
0.5	0.62	1.68	0.24
1	0.66	1.61	0.25

1b: $\gamma = 10, \rho = 4; C = 0.05$

μ	e	w	u
0.1	0.54	1.93	0.21
0.5	0.61	1.59	0.26
1	0.65	1.49	0.28

1c: $\gamma = 5, \rho = 1; C = 0.8$

μ	e	w	u
0.1	0.43	3.57	0.27
0.5	0.55	2.85	0.29
1	0.61	2.58	0.29

1d: $\gamma = 10, \rho = 0; C = 1.5$

μ	e	w	u
0.1	0.53	1.90	0.21
0.5	0.62	1.89	0.20
1	0.67	1.87	0.20

5 Conclusion

When new ICTs are adopted, organizations change and jobs change. The telegraph, the telephone, and a host of other technologies made it feasible to coordinate elaborate planned divisions of labor involving hundreds of thousands of employees in big corporations, and tens of millions in the planned economy of the Soviet Union. The rigid bureaucratic structures for which the mid twentieth century was known were a reflection of the ICTs of the day, which produced imprecise plans and allowed for only slow adjustments. Microprocessors and other, more recent, developments in ICT have made possible more flexible planned systems. All of these changes in technology and organization structure change the relative power that different employees exercise at work. On the one hand monitoring improves, on the other the scope for decision making may increase. ICTs may empower or dis-empower, and the adoption of ICTs does not, *a priori*, tell us how relative earnings will change.

However, the salient facts before us - the rise in earnings inequality; the increase in between-establishment, firm and industry earnings dispersion; the patchy adoption of HIWPs and the association between HIWPs and earnings; the positive relationship between ICTs and effort – can be explained in terms of power.

The US and the UK along with some (but by no means all) other countries have experienced an increase in earnings inequality. A part of this increase can be "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 the skill that is being compensated. It is our hypothesis that the important changes 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 employees tend to have lower levels of measured skill, this increased differential shows up empirically as an increased return to skill within organizations. The return to measured skill, however, does not pick up much of the increase in the variance of earnings between establishments, firms, and industries. It is more satisfactory to explain these unexplained differences in terms of power rather than unobserved skill, for several reasons. One is the positive relationship Green finds between ICTs and effort. Another is the positive relationship between HIWPs and earnings, together with the uneven adoption of HIWPs across firms and industries.

Our formal model in this paper has obvious weaknesses and can be extended in many directions. A model, however, is useful to check the logic of the intuitive argument. In principle, a tendency for earnings to polarize could be undone by induced changes in employment and the associated fallback positions. The model shows that in fact the polarization in earnings may extend to employment and effort: PBTC may generate a pattern of increasing effort, declining employment and falling wages for low-skill workers.

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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.[7] Let e_L and e_H be orderings defined by

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

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

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

Let the production function before technical change be given by

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

and assume that

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

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

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

Note that if increased monitoring ability helps to squeeze wages and / or raise effort, $A > 1$ is not necessary to make the change profitable.

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 complete 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 $x = rU$, the objective function can be rewritten

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

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

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

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 the increase 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 whether or not $\bar{\delta}$ depends on $\bar{e}$, since average effort is itself determined by $\bar{w}, b$ and u, we have

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

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

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

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

where $s = E(\frac{1-\exp(-rT_u)}{r})$ 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. Thus, s is an increasing function if u. Using (B1)-(B2) it follows that

$$x = (w - v(e))\frac{p - rps}{p + s - rps} + b\frac{s}{p + s - rps}$$

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 (15)-(18)

The functional forms are given by

$$\frac{p'}{p} = \lambda(e,\mu) = \frac{\mu}{e} \tag{C1}$$

$$v(e) = e^{\gamma}, \gamma > 1 \tag{C2}$$

$$h(\bar{w}, u, b) = ub + (1-u)(\bar{w} - \bar{e}^{\gamma}) \tag{C3}$$

Using (C1)-(C2), the first order condition (2) can be written

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

or

$$e = [\frac{\mu}{\mu+\gamma}(w-h)]^{1/\gamma} \tag{C4}$$

It follows that

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

The firm's first order condition (5) yields

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

or

$$w = \frac{\gamma}{\gamma-1}h \tag{C5}$$

In equilibrium, $w = \bar{w}$ and $e = \bar{e}$, and using (C3)-(C5), we get

$$h = \frac{b(1-u)}{1-(1-u)(\frac{\gamma}{\gamma-1} - \frac{\mu}{(\gamma-1)(\mu+\gamma)})}$$

6.4 Appendix D: Proof that wages or employment must fall

Differentiating (15)-(17) totally, we get

$$\frac{d\log e}{d\log\mu} = \frac{1}{\gamma}\frac{d\log w}{d\log\mu} + \frac{1}{\mu+\gamma} \tag{D1}$$

$$\frac{d\log w}{d\log\mu} = -C_1\frac{d\log N}{d\log\mu} - C_2 \tag{D2}$$

where

$$C_1 = \frac{1}{u} + \frac{\frac{\gamma}{\gamma-1} - \frac{\mu}{\mu+\gamma}\frac{1}{\gamma-1}}{1-(1-u)(\frac{\gamma}{\gamma-1} - \frac{\mu}{\mu+\gamma}\frac{1}{\gamma-1})}(1-u)$$

$$C_2 = \frac{(1-u)\frac{\mu}{\mu+\gamma}\frac{\gamma}{\mu+\gamma}}{1-(1-u)(\frac{\gamma}{\gamma-1} - \frac{\mu}{\mu+\gamma}\frac{1}{\gamma-1})}$$

The denominator in the expression for C_2 is positive (otherwise the fallback position and the solution for w would both be negative) and since $\gamma > 1$ the numerator in the second term of the expression for C_1 is also positive. Thus, both C_1 and C_2 are positive and - using (D2) - it follows that an increase in μ must lead to a decline in w or N.

If the two types of labor are substitutes ($\rho < 0$), an increase in e_L must lead to a rise in either w_L or N_L. To see this, assume that w_L falls. The wage cost w_L/e_L then must also fall and since, by assumption, the cost of high-skill labor is unchanged, it follows that $w_L N_L / w_H N_H$ must increase (since $\rho < 0$). By assumption, $w_H N_H$ is unchanged. Hence, N_L must increase, and it follows that w_L and N_L cannot both decline if e_L increases.