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DEPARTMENT OF ECONOMICS

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Information and communications technologies, coordination and control, and the distribution of income

by

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Abstract

We consider the links between information and communications technologies (ICTs) and the distribution of income, as mediated by problems of coordination and control within organizations. In the large corporations of the mid-twentieth century, a highly developed division of labor was coordinated and controlled with the aid of relatively underdeveloped ICTs. This created a situation in which the options of top management were constrained while the individual and collective power of lower paid workers was enhanced. Only in the late twentieth century, when the microprocessor and related technologies transformed the information systems of organizations, did improvements in the tools of coordination and control race ahead of the growing demands of coordination and control. These technological changes have reduced the power of lower-paid employees, increased that for higher-paid employees, and led to an increase in income inequality. Thus, the more important aspects of new technology relate to the 'power-bias', rather than the 'skill-bias', of technological change.

JEL numbers: J31, O33

Key words: communications technology, power-biased technical change, inequality, work intensity, efficiency wage.

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1 Introduction

From 1940 to 2000, income inequality in the United States traces a sort of lop-sided U, falling abruptly in the 1940s and then rising, slowly in the mid 1950s and 1960s, more rapidly from the late 1970s onwards (Lindert, 2000; Kopczuk, Saez and Song, 2007). What the high-income households lost in the 1940s was largely property income, while what they gained from the late 1970s onwards has been wage and, to a lesser extent, entrepreneurial income (Piketty and Saez, 2007). Evidence from a variety of sources suggests that a similar "great compression" took place in other industrial capitalist economies in the 1940s, as did the replacement of property with wage and entrepreneurial income (see, e.g., Moriguchi and Saez, 2007; Piketty et al., 2006). However, in many countries, the compression of the income distribution has not been reversed, or was reversed later and less dramatically than in the US.

Many explanations have been offered for parts of this great U turn, and a few explanations have attempted to encompass all of it. Among economists, the hegemonic explanation for increased income inequality from the 1970s onwards was, until recently, skill-biased technological change (SBTC). Even by generous readings, however, SBTC cannot account for the extreme rises in wage income for the top one percent, nor can it account for the abruptness of the compression in the first place.

A second class of explanations attributes the compression, and de-compression, to institutional changes. Many of these - changes in tax rates, social insurance, minimum wage legislation, the legal framework of industrial relations, and the organizational reach of trade unions - came just before or just after the second world war. Wartime mobilization itself has often been seen as a spur to egalitarianism, both in attitudes and in institutions. And, clearly, the US and other countries in which income inequality rose so quickly from the late 1970s onwards saw, in that period, sharp reversals of some of the equalizing institutional changes of the great compression itself: the Reagan and Thatcher revolutions, and similar waves of liberalization in the other Anglophone countries. The large contribution of institutional changes to the fall and rise of inequality is undeniable, and yet these changes raise at least as many questions as they answer. War may, as a rule, be a social leveler, but the leveling is not always cemented with durable institutional changes. Even in the US, where the great compression was relatively short-lived, inequality continued falling for nearly a decade after the war, and pre-war levels of inequality were not reached again until the 1980s. Why did the leveling institutions last as long as they did, and why did a great wave of liberalization, and rising inequality, sweep the English-speaking industrial economies around 1980? And why did the 1940s also see a reduction in inequality in neutral countries, such as Spain (Alvaredo and Saez, 2006), and Sweden (Roine and Waldenstrom, 2006)?

Our argument in this paper is that changes in information and communications technologies (ICTs) used in workplaces contributed to the fall and rise in American inequality. These same technologies tend to be the focus of the SBTC literature, but contrary to the

SBTC hypothesis, we argue that the path from technology to distribution runs through technology's effects on agency costs, rather than skills. We accord a central role to institutions, but we see the institutional changes in question as partly endogenous. Our analysis owes a great deal to two distinct strands of literature. One of these is a literature on the changing organization of production, both within and between firms, with an emphasis on the information systems required for coordination and control (Chandler, 1977; Beniger, 1984; Yates, 1989). The other is the literature of agency - the formal study of the costs of controlling individual and collective employee behavior when contracts are incomplete (Alchian and Demsetz, 1972; Bowles, 1985; Gintis and Ishikawa, 1987).[1]

We argue that the compression of incomes in the 1940s was in part a response to problems created by the expansion of managerial business in the preceding decades. The leveling of incomes was a result of the limitations of the available information and communications technologies for coordination and control of these new, large enterprises. In ways that we detail below, the burdens of coordinating large, complex, and geographically dispersed companies enhanced the bargaining power of those lower in the hierarchy, and reduced that of top managers. From the 1970s onwards, advances in ICT improved coordination and control, reducing the agency rents accruing to those lower in the corporate hierarchies. The flexibility that the new ICTs brought also created new rents for those at the top of the hierarchies.

Following our terminology in Skott and Guy (2007a), we refer to changes in the relative ability of different groups to extract rents as a result of changes in workplace technology as *power biased technological change* (PBTC).

The rest of this paper is organized as follows. Section 2 lays out the relationship between information systems and agency in the operation of large organizations. Section 3 presents the argument for power-biased technological change in the mid-twentieth century, and for the inversion of this power bias in the late twentieth century. Section 4 discusses the implications of the technological changes for the power of managers. Section 5 uses a small model to analyze the effects of PBTC in a more formal setting. Section 6 briefly considers the relation between skill and power, and the relationship between the intra-firm issues addressed elsewhere in this paper and institutional change is broached in Section 7. Section 8 offers a few concluding comments.

2 Communications technology and problems of coordination and control

Economic growth is associated with an increasing division of labor, for the familiar reasons given by Adam Smith (1776), and any division of labor creates a need to coordinate the various specialized workers involved. For this reason, Machlup (1962) tells us, economic

[1] In its emphasis on institutions and relative power, our analysis has affinities with a number of other contributions, incl. Freeman (1996), Gordon (1996), Howell and Wieler (1998), Levy and Temin (2007).

growth comes with a growing share of work being devoted to information tasks - the overhead costs, if you will, of the division of labor. Moreover, as the division of labor grows, the economy's information requirements change qualitatively as well as quantitatively: we do not simply have more mercantile accounts in the manner of 15th century Venice, but different kinds of accounts - cost accounting, capital accounting, and complex financial instruments.

In the late nineteenth century, as a result of growing markets and new production technologies, there were gains to be had from creating large companies. Within a large company, some subset of the increasingly elaborate division of labor was carried out in a deliberately coordinated way - Chandler's (1977) visible hand.

There are important differences between visible and invisible hand coordination, but both hands rely on the reduction of the unstructured knowledge held by many different people to common and communicable forms that we call *information*. Hayek's (1945) information-theoretic reading of markets is instructive here: he maintains that the market's efficiency advantage over the central plan lies in its ability to distill vast amounts of local knowledge (what Polanyi (1962) calls tacit knowledge) into a single price vector. Yet, similar, if less extreme, reductions in the dimensionality of information take place within planned systems, including firms: the creation of standard categories and measures, whether for products, people, or processes, necessarily omits or distorts some features that might be salient, but this is a cost of establishing communication between offices in an organization, and in so doing facilitating coordination and control. Weber (1968) called such a reduction in the dimensionality of information "rationalization". Beniger (1986), describing the same phenomenon in the language of computer science, regards an organization's rules, procedures and annual budgets as ways of "pre-processing" information: fixed rules economize on information processing. [2]

Rationalization is a feature of the bureaucratic - and, to Weber, *rational* - organization, which we associate today with inflexibility. Inflexibility can reduce the need for the communication and processing of information. Consider the pioneering of modern management by early railroads: trains were unable to communicate with one another, and collisions were prevented by the adoption of roles and rules. In the 1850s, a train on the Boston and Worcester Railway could not move without the authorization of the conductor - an employee who directed this costly and dangerous collection of equipment by virtue of office, which is to say a bureaucrat. The conductor was, in turn, bound by a strict set of rules: a westbound train was to stop in the station at Framingham, and could not proceed until an eastbound train had arrived on the opposite track (Chandler, 1977, p. 96). Doubtless such a system caused many inefficiencies, as a delay to one train meant a delay to the other, but the predictability created by such rules had clear benefits. Two

[2] Rationalization and pre-processing are also evident in the *routines* emphasized by Simon (1957) in his discussion of bounded rationality. Bounded rationality is usually explained with reference to the cognitive limits of individuals. Simon uses the concept, however, to explain behavior within organizations. In this light, it is worth noting that while routine- or rule-based behavior in organizations can reflect inherent human cognitive limitations, it can also reflect technological limits to communication and computation.

aspects of this are interesting to us. One is that rule-based predictability - and inflexibility - substituted for communication. The other is the contrast between that early railway, and transport systems both before and after. Systems before - canal boats, wagons, ships at sea and so on - required less coordination than rail systems, and the individuals in charge of the different vessels were not bound by such detailed rules or procedures. Rail systems today retain very tight rules and procedures - leaving, if anything, less room for judgement by a train's conductor - but improved ICTs (scheduling and signalling systems) allow far greater flexibility in the disposition of trains.

To draw a more general lesson from this example, consider the development of other large businesses in the wake of the railway. Geographically dispersed activities were coordinated with the aid first of the telegraph and later with voice telephony. Both are high-speed communications technologies, but ones which suffer from very low bandwidths and no direct connection with any information storage or processing system. For the telegraph to be of use in discussing, say, the purchase of some materials or merchandise, any relevant technical specifications had to be already known between the parties. This constraint was relaxed somewhat with the telephone - a fact often credited with furthering the spatial separation of operations within companies in the early twentieth century - but when compared with the torrent of technical specifications and market information that can pour down a strand of cable today, the world of the telephone looks much like that of the telegraph. Such communications systems did not lend themselves to real-time processing, and this contributed to a heavy reliance on pre-processing.

It is plain from the historical record that, from the start, large companies were constrained by their technologies of coordination and control. Beniger (1986) describes what he calls a "crisis of control" in the mid-19th century; response to this crisis stimulated the development and application of new ICTs. Yates (1989) aptly describes this period as one in which "control through communication" developed. Cortada (1993) chronicles the development of mechanical and electro-mechanical tabulating machines, the primitive number-crunching ancestors of the computer.

Effective coordination and control is a moving target: ICTs and their applications improve, but the division of labor becomes more elaborate. Jonscher (1994) provides evidence, however, that in the 1970s and 1980s, there was a qualitative advance in the pursuit of improved coordination and control. In that period, the microprocessor and related technologies made it possible to integrate information systems with systems of production and of service delivery. For Jonscher, this presents itself as a problem of data classification: through 1970, he is confident in classifying occupations as information work and non-information work; from 1980, he finds this impossible. For us, the breakdown of these categories reflects a breakthrough in coordination and control.

3 Coordination, control, and the power of workers

The scale of planned activity together with the limits of ICTs in mid-twentieth century organizations worked to compress the distribution of income by empowering workers, and dis-empowering managers.

We begin with the workers, and proceed later to the managers. The limitations of ICTs affect the power of workers in three different ways: first, through the managers' ability to monitor the *actions* of workers; second, because the inflexibility of the system - the heavy reliance on pre-processing - reflects the fact that managers lack information about the conditions (or, in the language sometimes used in formal models of uncertainty, the *state of nature*) in which the workers' actions take place; and, third, because many of the pre-electronic information flows within organizations were restricted to a small number of paths, literally defined by the paths of pieces of paper, which were vulnerable to hold-up by employees along the way.

Consider, for example, the case of retail clerks. The invention of the cash register in the 1870s provided a key control technology in retailing: it provided a way of ensuring that the money collected from customers matched the money a clerk handed over to her or his employer at the end of the day. It was little help in fighting collusion between clerks and customers (i.e., deliberate undercharging), and was only a crude instrument for measuring the work pace or productivity of the clerk. Over the ensuing decades cash registers proliferated, improved mechanically, were replaced by electro-mechanical versions, and then improved still further, but their functions remained the same. Such information as was collected from cash registers had to be summarized, manually, for each store in a multi-store company, and then entered, again manually, into the company's system of accounts. Not until the late 1970s, with bar codes and networked computing, was there a fundamental change in what the cash register *did*. With those changes, the cash register suddenly provided a substantial barrier to clerk-customer collusion, and provided fine monitoring of each individual clerk's productivity throughout the day. The same automatic data collection capabilities allow managers to monitor patterns of business throughout the day - that is, to know the state of nature in which the workers are acting. All of this information is fed to, and processed automatically by, a computer system which can make results available to managers at many levels of the organization. And, of course, such point-of-sale systems are just part of larger management information system which allows monitoring of employees and operations up and down the supply chain.

We see similar cases in financial services, for instance with the movement of customer service from desks in local bank branches to call centers.

These changes affect the power workers have in their relations with their employers. Power, as we use the term, means one party's ability to affect outcomes that matter for another. The power a worker has over an employer is a function both of the sensitivity of employer outcomes to the worker's actions - is the worker able to affect a large operation or a costly piece of equipment, or is her work independent and without much capital? -

and of the employer's ability to constrain the worker's actions through monitoring and intervention.

High costs of monitoring individual workers, or the employer's ignorance of the state of nature in which they operate leads, *ceteris paribus*, to higher wages. Poor information systems reduce the match between contractible proxies for a worker's effort or output, and the effort or output itself; the power of workers is enhanced and the level of efficiency wages tends to increase. This holds whether the latter is understood as taking place in a gift exchange (Akerlof 1982); or in an adversarial relationship in which performance is enforced through a combination of employment rents, and a threat of dismissal following the principal's subjective evaluation of the agent's performance (Bowles 1985; Gintis and Ishikawa 1987; Shapiro and Stiglitz 1984). We examine this point in detail with the model and simulation presented below.

The employer's imprecise knowledge of the state of nature also creates a functional role for labor unions. The inflexible and rule-bound firm often requires that low-level employees go beyond what their instructions require; bureaucratic organizations have been brought to a standstill by their employees "working to rule". If doing a good job requires working beyond - and perhaps even in violation of - the rules, or suggesting changes to the rules, employees may expose themselves to arbitrary retaliation from supervisors simply by doing a good job. Part of the voice function of the union is to ensure fair treatment in such circumstances. Freeman and Medoff (1984) gave this as a reason why unionized companies in the United States enjoy higher productivity than non-unionized ones. [3]

Let us turn, finally, to the question of the *flow* of information. Management of the flow of materials is at the center of Chandler's analysis of the large corporation, and its ability to achieve economies of speed. The vulnerability of mid-twentieth century production systems to interruptions of this flow is a well-understood factor in industrial relations: by sitting down in a few factories in 1937, workers at General Motors were able to bring a large part of the North American manufacturing operations of this company - and many of its suppliers - to a halt. The vulnerability of such production systems is often understood as a result of the inflexible, single purpose nature of the capital stock (Piore and Sabel, 1984). Yet economizing on information processing was also a factor in the design of these systems: the single path flow of goods and fixed purpose machines also formed part of a control system which made it possible to monitor the pace of work without benefit of elaborate information systems; this is the distinction Edwards (1979) makes between

[3] Fairris (1997) argues that it was the productivity benefits of voice that led to an organized movement among American employers, during the first World War, to establish company-sponsored employee associations; many of these associations were later supplanted by unions, which took over the voice function and combined it with such functions as wage bargaining. More recent evidence comes from Black and Lynch (2001), who study the effects of high performance work practices on productivity in American manufacturing. High performance work practices involve problem-solving and decision-making by individual workers and by teams, at some cost to central control. Black and Lynch's finding is that such practices bring productivity benefits only when unions are present; they attribute this to union voice, consistent with the analysis here.

mechanical and bureaucratic control.

Like the single-path flow of materials in mass production, the vertical integration characteristic of mid-twentieth century has an information systems element. The same ICT limitations which make the internal plans of a company rigid and imprecise also limit what is measurable for the purposes of inter-firm contracts. We should expect this to further improve workers' collective bargaining power, and to compresses earnings differentials between workers. We expect enhanced bargaining power because each act of vertical integration - whether for the supply of high tech parts, or taking catering and cleaning in-house, creates some degree of lock-in that would not be present if the service were purchased on a competitive market.[4] Since the late 1970s, however, Chandlerian economies of speed have been routinely realized in coordinated multi-firm networks. In this and other respects, the greater flexibility of information flows permits greater flexibility of organizational configuration; the world in which information can be directed down any number of paths at will is also a world in which the supply paths of goods and services can be shifted with relative ease, thus weakening workers' bargaining power.

Networked production's most noticeable manifestation is cross-border, and cross-ocean, outsourcing. Within industrial countries, it seems clear both empirically and by standard Stolper-Samuelson reasoning, that this increases inequality, although the size of this effect is disputed (see, e.g., Wood, 1994; Leamer, 1996). Although much of this analysis is framed with reference to trade in general, the point here is that the more rapidly developing areas of trade - what economists call intra-industry trade - is occurring within planned manufacturing, procurement and distribution chains over distance (Gereffi 1999; Gereffi, Humphrey, and Sturgeon 2005).

4 The power of managers

Organizational inflexibility empowers workers, and for the same reasons it dis-empowers managers. We can see this if we view the manager's employment relationship as we viewed the employment relationship of the worker, absent questions of collective action. The logic of agency models, including the efficiency wage model we use below, is that wages are an increasing function of the sensitivity of the employer's outcomes to the manager's effort. (In this we assume that there is a principal to set the manager's wage and to threaten sanctions for non-performance.) If the nature of organizational inflexibility is that few changes get made or attempted, and that competitors who are similarly inflexible demand less in the way of rapid response, the marginal product of the manager's effort should be less, and remuneration should be less.

With a flexible organization in an environment of other flexible organizations, managers

[4] Vertical integration should also be expected to compress overall differentials among workers simply because it is known that organizations compress income differentials internally, relative to the market; the reasons for this are contested, but the empirics are clear (Frank 1985; O'Shaughnessy, Levine, and Cappelli 2001).

have more consequential choices to make. Moreover, the ICTs which facilitate the flexibility, in part by enhancing the monitoring of workers and of the states of nature in which workers make decisions, can do little to monitor the more complex and non-comparable actions and options of executives.

For these reasons, the enhanced flexibility of organizations can help to explain the astonishing secular increase in executive pay in the US, Britain, and some other countries, over the past thirty years. Others have attributed this increase - and the higher levels of executive pay in the liberal market economies - to *financialization* (O'Sullivan, 2001). Financialization in this context refers to the adoption of a normative standard of maximizing shareholder wealth as the proper objective for all firms and to the spread of hostile takeovers and leveraged / private equity buyouts as means of enforcing financial discipline on managers. Explanations for financialization include the growth of pension funds and other institutional investors, providing a new source of monitoring for corporations in the liberal market economies, and an ideological or cultural change wrought in the profit and productivity slump of the 1970s. While both of these explanations have merit, we find a third (non-exclusive) explanation emerging from our analysis: namely, that organizational modularity makes many different pieces of any large organization potentially marketable, and for that reason makes the top executive's job into one of managing an investment portfolio of business units. A menu of such investment decisions is another form of executive empowerment, and should lead to higher pay.

Whatever the cause of financialization, the ongoing market for companies and parts of companies creates similar agency rents for lawyers, investment bankers, and others involved in these deals. Together with the rise in the pay of corporate executives, this helps explain the extraordinary rise of the incomes - and, specifically, the *wage* incomes - of the top one per cent since 1982.

5 Modelling PBTC

An efficiency wage model provides a framework for examining some of the issues of coordination and control that are the focus of this paper.[5] Consider an economy with three inputs, capital (K) and two types of labor (N_L and N_H), and let the production be given by

$$Y = F(e_L N_L, e_H N_H, K)$$

where e_i denotes the effort of workers of type i. Using standard assumptions, type-i workers decide their effort by maximizing an objective function

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

[5] This section draws on, and extends, material from Skott and Guy (2007a).

where $\bar{w}_i, u_i$ and b denote the average wage, the unemployment rate and the rate of unemployment benefits.[6]

The function $v(e_i)$ describes the disutility associated with effort. In order to focus more clearly on the effects of changes in relative power, we assume symmetry between the two groups of workers with respect to the $v-$function, and in the calculations below we use the specification,[7]

$$v(e_i) = e_i^{\gamma}; \gamma > 1 \tag{1}$$

The function $p^i(e_i)$ captures the effect of effort on the expected remaining duration of the job. An increase in effort reduces the risk of being fired (that is, $p^{i\prime} > 0$), and we use a constant-elasticity specification,

$$\frac{p^{i\prime} e_i}{p^i} = \mu_i \tag{2}$$

This specification can be seen as a log-linear approximation of the p^i-function around the equilibrium solution for e_i. The parameter μ_i, which describes how well workers of group i can be monitored, is an inverse indicator of power. A high value of μ_i implies that workers are closely monitored, the firing risk is very sensitive to variations in effort, and workers have little power; small values of μ_i indicate that workers have high degrees of discretion in the sense that variations in their effort is likely to go undetected.

The function $h^i(\bar{w}_i, b, u_i)$, finally, represents the expected utility in case of job loss. The partial derivatives satisfy $h^i_{\bar{w}} > 0, h^i_b > 0$ and $h^i_u < 0$ under all standard assumptions. We use the specification associated with the intertemporal interpretation of the worker's maximization problem in Skott and Guy (2007a):

$$h^i = \frac{(r+\delta)u_i}{ru_i + \delta} b + \frac{\delta(1-u_i)}{ru_i + \delta}(\bar{w}_i - v(\bar{e}_i)) \tag{3}$$

where $\bar{e}_i$ is the optimal effort associated with the wage $\bar{w}_i$. The parameters r and δ are the discount rate and the rate of job separations, respectively, and assuming symmetry in all respects other than power, both groups of workers have the same discount rate and the same average rate of separations.[8] 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 expect to be 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.

[6] A simple intertemporal optimization model reduces to a special case of the maximization problem (Skott and Guy, 2007a).

[7] The parameter restriction $\gamma > 1$ is needed since otherwise the firm's unit cost would decrease monotonically as wages increase.

[8] Differences in the elasticities of the $p-$ function do not imply that the two groups cannot have the same average firing rates in equilibrium (see Skott and Guy (2007a) for details).

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

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

and, using the functional forms for v and p in equations (1)-(2), this condition implies that

$$e_i = [\frac{\mu_i}{\mu_i + \gamma}(w_i - h_i)]^{1/\gamma} \tag{4}$$

Wage and employment are set by the firm. Looking at the wage first, the standard Solow condition implies that

$$\frac{e_{iw} w_i}{e_i} = 1$$

and, using (4), we get

$$w_i = \frac{\gamma}{\gamma - 1} h_i \tag{5}$$

$$e_i = \left[\frac{\mu_i}{\mu_i + \gamma}\frac{1}{\gamma - 1} h_i\right]^{1/\gamma} \tag{6}$$

The demand for labor is determined by the first-order conditions

$$w_i = F_{N_i}(e_L N_L, e_H N_H, K)$$

and the specification of the production function is critical for the implications of the model. It is generally accepted that the elasticity of substitution between capital and labor is well below unity (see Klump et al. 2007 for a recent study), but we know of no attempts to examine the elasticity of substitution between groups with different workplace power.

As argued in section six below, power and skill may be correlated, and the labor-labor elasticity for different skills is sometimes taken to be above unity. The evidence, however, is weak. Katz and Murphy (1992) estimate an elasticity of 1.41 between high- and low-skill workers (college and above vs high-school or less) but also point out that they are "somewhat skeptical of estimates of σ recovered from 25 nonindependent time series observations", and a range of elasticities - including an estimate of 0.5 - is consistent with the data in their study. Another recent study, Card et al. (1999), obtains very low estimates (all at or below 0.5), and the survey of earlier work in Hamermesh (1993) does not present a clear picture. These studies, in any case, focus on skill rather than power, and power, unlike skill, is a job attribute. For present purposes it is therefore the elasticity of substitution between jobs that matters, and the presence of mismatch in the job market may generate a spurious impression of substitutability: even if there were to be perfect complementarity between different jobs, the presence of mismatch - some high-skill workers having low-skill jobs - could give the appearance of substitutability.[9] Thus, we suspect the

[9] Let

$$Y = \min\{\theta H, L\}$$

empirically interesting case to be one in which the elasticity of substitution is well below unity, but a nested CES production function allows us to consider several cases,

$$Y = A\{\frac{2}{3}([\frac{1}{2}(e_L N_L)^{-\rho_1} + \frac{1}{2}(e_H N_H)^{-\rho_1}]^{-1/\rho_1})^{-\rho_2} + \frac{1}{3}K^{-\rho_2}\}^{-1/\rho_2}$$

With this production function, the labor demand equations can be written

$$\begin{aligned} w_i &= \frac{A}{3}e_i^{-\rho_1}N_i^{-\rho_1-1}[\frac{1}{2}(e_L N_L)^{-\rho_1} + \frac{1}{2}(e_H N_H)^{-\rho_1}]^{(\rho_2-\rho_1)/\rho_2} \\ &\quad \{\frac{2}{3}([\frac{1}{2}(e_L N_L)^{-\rho_1} + \frac{1}{2}(e_H N_H)^{-\rho_1}]^{-1/\rho_1})^{-\rho_2} + \frac{1}{3}K^{-\rho_2}\}^{-(1+\rho_2)/\rho_2} \end{aligned} \tag{7}$$

To close the model, we impose the equilibrium condition that $w_i = \bar{w}_i$, and introduce symmetric and inelastic labor supplies. Normalizing these supplies at unity, we have

$$u_i = 1 - N_i \tag{8}$$

The solutions for wage rates, unemployment rates, work intensities (effort levels), and profitability can be derived using (3) and (5)-(8), and we are in a position to examine the effects of PBTC or, in terms of the model, changes in the parameters μ_L and / or μ_H. If we include top-management with profit recipients, then the stylized picture suggested by our argument in sections 2-3 is one with a significant rise in μ_L over the last 30 years and more modest changes or rough constancy of μ_H.

The variations in μ_L in Table 1 are within (what we consider) the plausible range,[10] and we use a discount rate of $r = 0.05$ and a rate of separations of $\delta = 0.2$ (implying

where H, L are the numbers of high and low skill jobs that are filled. Assuming that some low-skill jobs are filled by high-skill workers and / or some high-skill jobs by low skill workers, we have

$$\begin{aligned} H &= N_{HH} + N_{LH} \\ L &= N_{HL} + N_{LL} \end{aligned}$$

where N_{HH} and N_{HL} are high-skill workers in high- and low-skill jobs, respectively, and N_{LL} and N_{LH} are low-skill workers in low- and high-skill jobs. Profit maximizing firms do not employ idle workers, and it follows that $\theta(N_{HH} + N_{LH}) = N_{HL} + N_{LL}$ and $Y = \theta(N_{HH} + N_{LH})$. Hence,

$$(\theta + 1)(N_{HH} + N_{LH}) = N_{HH} + N_{LH} + N_{HL} + N_{LL}$$

and

$$\begin{aligned} Y &= \theta(N_{HH} + N_{LH}) = \frac{\theta}{\theta+1}(N_{HH} + N_{LH} + N_{HL} + N_{LL}) \\ &= \frac{\theta}{\theta+1}(N_H + N_L) \end{aligned}$$

where N_H and N_L denote the employment of high and low skill workers, respectively.

A more complete model could include mismatch, along the lines of Skott (2006), as well as changes in power. This, however, would complicate the analysis significantly.

[10] The intertemporal interpretation of the worker's maximization problem implies that $p = 1/(r+\delta)$ and hence that $p'e/p = -\frac{e}{r+\delta}\frac{d\delta}{de} = -\frac{\delta}{r+\delta}\frac{d\log\delta}{d\log e}$ where δ is the rate of job separations. Job separations happen

that just over 18% of workers will lose, or choose to leave, their jobs within one period). The parameter γ in the utility function must be greater then one (cf above), and the qualitative results appear to be insensitive to the precise value. The table uses $\gamma = 5$. The rate of unemployment benefits ($b = 0.008$), the capital stock ($K = 0.1$), and the productivity parameter ($A = 0.5$) have been chosen to get employment rates of about 0.75, a replacement rate of about 1/3, and a capital-output ratio of about 2. With respect to the production function and the elasticities of substitution, finally, the table assumes that the capital-labor elasticity is $\sigma_2 = 0.5$ while three different values of the labor-labor elasticity σ_1 are considered; a benchmark value of $\sigma_1 = 0.5$, a high substitutability case with $\sigma_1 = 1.5$ and a low substitutability case with $\sigma_1 = 0.2$.

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

1a: Benchmark case, $\sigma_1 = \sigma_2 = 0.5$

μ_L	e_L	w_L	u_L	e_H	w_H	u_H	π
0.1	0.156	23.4	0.255	0.156	23.4	0.255	20.2
0.4	0.200	21.7	0.256	0.159	26.2	0.241	24.0
0.8	0.224	20.6	0.251	0.161	27.5	0.236	25.9

1b: Strong labor-labor complementarity, $\sigma_1 = 0.2, \sigma_2 = 0.5$

μ_L	e_L	w_L	u_L	e_H	w_H	u_H	π
0.1	0.156	23.4	0.255	0.156	23.4	0.255	20.2
0.4	0.195	19.1	0.280	0.162	28.8	0.231	23.6
0.8	0.216	17.0	0.294	0.165	31.2	0.224	24.9

1c: Strong labor-labor substitutability, $\sigma_1 = 1.5, \sigma_2 = 0.5$

μ_L	e_L	w_L	u_L	e_H	w_H	u_H	π
0.1	0.156	23.4	0.255	0.156	23.4	0.255	20.2
0.4	0.206	24.9	0.237	0.155	23.1	0.257	24.4
0.8	0.234	25.3	0.222	0.555	22.8	0.259	26.7

When there is labor-labor complementarity (the benchmark case with $\sigma_1 = 0.5$ and the strong complementarity case with $\sigma_1 = 0.2$) workers with low power will be relatively low-paid. An increase in μ_L from $\mu_L = 0.4$ to $\mu_L = 0.8$ generates a decline in the absolute and relative wage of $L-$workers, and their work intensity increases (both absolutely and relative to that of $H-$workers); their relative employment declines and under strong complementarity, absolute employment declines too. Thus, the simultaneous increase in

for many 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 the elasticity of output with respect to e is the same as the elasticity with respect to N). It follows that μ will be less than one.

the relative wage and the relative employment of high-skill workers does not require an explanation in terms of SBTC. The table demonstrates that changes in power relationships (the PBTC hypothesis) can explain these observations too. The increase in work intensity, moreover, is in line with findings of increased effort in the UK and other industrial economies during the 1980s and 1990s (Green 2004); the standard SBTC approach sheds little light on these findings. Note finally that total profits (π) and the profit share ($\pi/(\pi + (1 - u_L)w_L + (1 - u_H)w_H)$) increase. In fact, in the benchmark case the proportional increase is higher for profits than for w_H, and the model can generate an explosion in managerial pay even if it is assumed that the share of top management in net profits is unchanged.

PBTC also produces an increase in wage inequality and increased profits in the case with good labor-labor substitutability ($\sigma_1 = 1.5$). The difference is that in this case low-power workers are high-paid, and to explain the observed increase in inequality over the last 30-40 years one would have to argue that new ICT has reduced the power of highly paid workers. This is implausible, and the empirical relevance of the model therefore hinges on the assumption of complementarity between high- and low-power jobs.

The model clearly has many limitations. One of them is that it is limited to changes in monitoring, which is just one avenue by which ICTs can affect the workplace power of employees; another that it deals only with individual effort choices and wage bargains, abstracting from any form of collective action. Thus, while the model may provide an acceptable approximation of current wage setting in the US, UK, and other liberal market economies (using the term in the sense employed by Hall and Soskice (2001)), it is less appropriate for countries in which wage bargains are more likely to be collective.[11]

6 Skill bias?

In our discussion thus far we have focussed entirely on PBTC: a causal account running from ICT to coordination and control, from coordination and control to the relative power of different classes of employee, and from the distribution of power to the distribution of earnings. A more widely held theory connects new technology with the earnings distribution through the market for skills.[12]

In formal models of earnings determination, the distinction between skill and power

[11] Unions influence working conditions as well as wages. 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).

[12] The source of the bias - SBTC or PBTC - can have important 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 (Skott and Guy 2007b; an earlier Marx-inspired literature includes Bowles (1989) and Green (1988)).

seems 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 are often been conflated. Yet, while agency reasoning is widely used to explain cross sectional differences in earnings, it is seldom employed to explain changes in those differences over time. In most of the vast literature on skill, earnings, and technology, power is either conflated with skill, or ignored completely.

The habit of conflation owes something to Braverman (1974), who does not conflate skill and power but does make them part of the same cause and effect relationship: he 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 became 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.

The practice of either ignoring power or conflating it with skill may owe simply to discretion being the better part of valor: trying to distinguish power and skill using available data is almost never straightforward. 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. Similarly, many studies of the effect of ICTs on the labor process in growing parts of the service sector, such as retailing, banking, telecommunications and customer service call centers provide evidence 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 Lafkas 2003). Card and DiNardo (2002) have argued that SBTC cannot explain why US earnings inequality did not continue to rise in the 1990s, in the face of continued adoption of new technologies; yet this can pose problems for PBTC, as well.

What we argue here is that SBTC falls down most clearly in its inability to provide a convincing story of endogenous institutional change. This is a major problem for Goldin and Katz (1998), for example, when they attribute the fact of the great compression in the US to the rapid spread of high school education (a source of skill), but its suddenness to other institutional changes which they must treat as exogenous. Similarly, when the decompression speeds up in the late 1970s, it is helped along by a series of institutional changes. Why should institutional changes, in both cases, accelerate the market trend?

7 Institutions

In the discussion above, we considered ways in which technologies of coordination and control affect the bargaining power of individual workers and managers, and of groups of workers, at the level of the firm. What of the institutional environment in which the firm and its employees bargain?

There is little question that institutional changes played major roles in both the reduction of inequality in the 1940s, and its rise since the late 1970s. Many of these institutional changes can be viewed as complementary to the within-firm changes in bargaining power we have described. In the US, for instance, federal legislation in the late 1930s strengthened labor unions, extensions of social insurance improved the bargaining fall-back of workers, and regulation restricted competition in many industries. The same can be said for workplace health and safety, minimum wage, and statutory overtime pay. Later, in the de-compression period, the enforcement of federal labor relations law weakened, industries were de-regulated, and the real value of the federal minimum wage was allowed to fall. DiNardo et al (1996) find that de-unionization and the falling real value of the minimum wage account for a substantial share of the rise in US wage inequality between 1979 and 1988.[13]

In many countries of course, the great compression of the 1940s was not matched by a de-compression in the late 20th century. Recent studies of this question have been framed in a comparative capitalisms framework which distinguishes between "liberal" market economies (LMEs) and other, more or less "coordinated" market economies (CMEs). The former coincide almost exactly with the English-speaking industrial economies, while the various shades of the latter are found in continental Europe and East Asia. Mann and

[13] An insitutional explanation raises questions concerning the simultaneous increase in the relative wages and employment of highly paid (high-skill, high-power) workers. This simultaneous change could be accommodated by the PBTC model in section 5. It can also, however, be accounted for, in models with neither skill nor power biases. If the labor market is characterized by 'overeducation' - that is, a mismatch with many high-skill workers accepting jobs for which their skills are not needed - an increase in the relative wage of high-skill *jobs* need not generate a decline in the relative employment of high-skill *workers* (Skott 2005, 2006; Sattinger 2006).

Riley (2007) show that Anglo-Saxon economies had lower income GINIs in 1950 than either continental European or Scandinavian economies; while the Anglo-Saxon economies got less equal over the ensuing 50 years, the other groups became more equal. The institutional configurations which have prevented de-compression in many countries are well explicated by Estevez-Abe et al. (2001), and by Mares (2001). They offer an explanation of how what Hall and Soskice (2001) call "coordinated market economies" came to have institutions of redistribution which have, so far, proved robust in the face of changes in technology and business organization. What they do not explain is why the compression *did* occur in the Anglo-Saxon economies, nor why it occurred broadly across the industrial world in the first place.

One could argue that the post-war survival, and intensification, of wartime redistribution resulted simply from the extension in the political arena of the power of organized labor.[14] Yet many of the countries in which the compression occurred were governed by conservative or center parties, without the support of unions; it occurred even in some fascist states where the union role in national politics had been effectively extinguished.

If our analysis in this paper is correct, the institutional changes that contributed to the great compression were facilitated by the needs of business. The modern, mid-twentieth century business enterprise offered substantial productivity gains, but those gains were conditional on the resolution of conflicts within firms. Here it is necessary to step back from the formal modeling of bargaining, in that such models describe equilibrium end-states and can create the impression that such end-states are arrived at without cost. The companies we describe, with worker power created by limited management information and by product and information flows subject to hold-up, are sites of conflict. Institutions designed to minimize the cost of this conflict did so by accommodating the bargaining positions formed by the information structure of the firms.[15] Thus, our analysis in this paper provides an argument, rooted in relationships *within the firm*, for the parallel compression of the income distribution of the United States and most of industrial world. Unlike some of the European economies, the United States never developed the strong interlocking institutional constraints on earnings distribution, described by Estevez-Abe et al. (2001)). Instead, in the early post-war era of American mass production the constraints and incentives provided by the managerial firm itself meant that only a relatively weak set of institutional constraints was needed to effect redistribution.

[14] The influence of the cold war and the perception that the Soviet Union could present a viable alternative economic system may also have played a role.

[15] Eichengreen and Iversen (1999) and Estevez-Abe et al. (2001) make an argument parallel to ours, with regard to the positive relationship between catch-up potential after wartime losses (proxied by the ratio of GDP per capita post-war and pre-war), and the formation of institutions for social insurance, skill formation and - in the event if not the design - redistribution.

8 Conclusion

The substantial productivity benefits of a planned division of labor - benefits derived from economies of scale, scope, and speed - brought the rapid emergence of managerial firms in the early twentieth century. The productivity gains were contingent, however, on solving problems of coordination and control within the firms. The limitations of the information systems employed for coordination and control created significant agency problems, both individual and collective, which on balance strengthened the bargaining power of lower-ranking and less-skilled workers. Moreover, the organizational inflexibility inherent in coordinating extensive divisions of labor with crude ICT reduced top managers' scope for action, thus limiting their agency rents. These factors had the potential, in a decentralized system of wage determination, to reduce inequality; however, they also had the ability, amply evidenced in the 1930s, to provide a setting for industrial conflict which dissipated many of the productivity gains promised by managerial enterprise, and in some cases might even threaten the larger social order. Under these circumstances, institutions which aided peaceful resolution of workers' claims were socially functional. The particular causal mechanisms by which this functionality came to be implemented is beyond the scope of this paper.

The relationship we propose between ICT and income distribution needs to be compared with a more conventional story, which connects the two through the market for skill. There is such a market, and there is no doubt that shifts in the supply of, and demand for, skills affects the distribution of income. The questions here are whether supply of and demand for skill provides the principal route by which changing technology explains the great U-turn in income distribution in the US and other liberal market economies between 1940 and 2000. There are a number of reasons for doubting that the market for skill can explain either the abruptness of the changes - particularly the onset of the compression - or the relative stability of the distribution in other periods.

Moreover, it is clear that institutional change played a large part at both the inception and the reversal of the great compression. If technological changes contributed to the compression through the labor market - whether via skills or via agency - was it just a coincidence that institutional changes were pushing the income distribution in the same direction? We do not need to fall back on coincidence if the institutional changes are produced endogenously by the same process that connects technology and the labor market. We argue that the agency problem - the imperative of resolving conflicting claims to productivity gains - provides good story of endogenous institutional change at both ends of the great compression, in a way that the skill story cannot.

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