Finnish Economic Papers – Volume 15 – Number 1 – Spring 2002

TECHNOLOGICAL CHANGE, LABOUR CONTRACTS AND INCOME DISTRIBUTION

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An overlapping-generations model is developed; human capital, embodied in education and general on-the-job training, is important, necessitating investments in the first period of work. Competition among employers combined with short-term contracting imposes an incentive constraint on the intertemporal wage payments which is costly due to creditmarket imperfections. Workers work too much and are paid too little in the first period. Exogenous technological change complementary with skills aggravates the wage distortion, thereby inducing compensating wage increases. Income taxes mitigate the distortions. (JEL: D91, J22, J24)

1. Introduction

Perhaps the most pervasive influence on contemporary societies is that exerted by the current technological evolution. Not only does it change our physical whereabouts, but it also affects the less tangible fabrics of society embodied in incentives, modes of interaction, and institutions.

This paper is an attempt to illuminate one channel through which technological change – indirectly by affecting incentives – may change the labour market. The paper was conceived under the influence of the debates about what may cause observed transformations of labour markets in the industrialised world, where technology has been accused of causing increasing inequality as well as increasing unemployment. The work was started with the premise that these accusations – as well as the knee-jerk response that the same was said in the beginning of the industrial revolution and has been proved wrong – are based largely on the tangible aspects of technological evolution and may be misleading.

The key idea from which we start building our model is that the hiring by firms of skilled labour, for a host of reasons, constitutes a substantial *investment*. The reasons may include on-the-job training, low initial productivity and learning, costs of building a team, or costs of developing personal customer relationships. If a major fraction of the gains from the initial investment can be appropriated by another firm by hiring the worker at a later stage (or if the worker can appropriate similar gains by becoming independent), firms making such investments will have strong incentives to protect them. Since in general it is not possible for a worker to commit his labour through long-term

* *I am grateful to Dan Anderberg and an anonymous referee for helpful comments. Most of this paper was written while I was visiting Department of Economics, Harvard University. Financial support from the Bank of Sweden Tercentenary Foundation is gratefully acknowledged.*

contracts, the measures taken by firms to protect their investments must take the form of distortions of the short-term contracts actually governing the employment relationship.[1] It seems likely that the importance of the initial investment increases with technological progress, and we will argue that this is indeed the case under mild conditions.

We will consider a simple overlapping-generations economy where skills are embodied in education and on-the-job training. The technology is taken as exogenous, and the driving assumption is that it is *complementary* with the skill-related attributes mentioned above in the sense of increasing their incremental returns. This is, arguably, a very weak assumption.

In this framework we show how technological progress is transmitted through requirements of on-the-job training to increasingly distorted wage profiles because of the inalienability of human capital and imperfect credit markets. In addition, we show that first-period work hours are distorted upwards by the same distortion. We develop our results in a partial-equilibrium framework, but in an Appendix we show that the results continue to hold in a fully closed two-sector model.

1.1 Background

The driving problem of this paper whould vanish if human capital could be perfectly collateralised. Indeed, it is well known from e.g. Becker (1975) that the solution entails the worker paying for *general* training by himself, or committing himself to his job by posting a *bond*. It is a common view that such possibilities are quite limited, but the issue still raises a modelling problem since *some* bonding possibilities may exist, and since it seems a bit arbitrary to simply rule them out.[2] The most obvious arguments against bonding involve workers' being credit-constrained, and the temptation by firms to fire workers just to appropriate the bond.[3] Even though the latter seems remediable by reputation effects, various kinds of asymmetric information have been found to make bonding less attractive.[4] We will focus on the credit constraint and take a middle road by assuming that workers have access to a credit market, where, however, borrowing is costly because of an interest-rate premium due to transactions costs and moral-hazard problems.

Conceptually, this paper draws on two strands of literature. First, there are a number of papers showing how wages provide an insufficient set of instruments in second-best environments. Examples include Salop (1979), who shows how turnover costs and a constraint that all workers must be paid equally lead to an equilibrium with involuntary unemployment, and Bester (1988), who compares labour-market equilibria with and without a credit market in a one-sector general-equilibrium model, finding that involuntary unemployment comes with credit-market imperfections. Moreover, the *efficiency wage* literature, e.g. Shapiro and Stiglitz (1984), exploits this logic; there, the wage level must simultaneously provide effort incentives and clear the labour market, and the result is involuntary unemployment. Rebitzer and Taylor (1995) analyse work hours in an efficiency-wage setting; they show that when workers are heterogenous, optimal contracts will specify wage-hours packages, and there will be too few short-hour jobs in equilibrium. Second, there is a growing literature on *complementarities*. Our work is close in spirit to that of Milgrom and Roberts (1990) in analysing the impact of exogenous technological change on a system with complementarities. They make heavy use of complementarities in

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[1] The legal restraint on long-term contracts on labour is an instance where incomplete contracting is imposed by law; for an up-to-date review of the theory of incomplete contracts and why they may arise in the absence of legal restraints, see Hart (1995).

[2] Dickens et al. (1989) provide a comprehensive discussion of why bonding seems to be rare in practice.

[3] An increasing wage schedule – facing similar appropriation problems – has been suggested by Lazaer (1981) as a means of providing effort incentives.

[4] Ritter and Taylor (1994) consider private information about firm quality, Hermalin (1990) considers private information about worker quality, and Chang and Wang (1996) consider a matching problem combined with asymmetric information between current and prospective employers; all find that fully exploiting bonding is not optimal.

their explaining the evolution of modern manufacturing, in particular the clustering of certain characteristics.

Clearly, we focus on one out of several channels through which technology may affect employment relationships, omitting a number of other forces at work. Obvious such forces are efficiency wages and career concerns by employees.[5] We also take the fact there are firms as exogenous; it has been argued, e.g. by Reich (1991), that one of the most conspicuous changes taking place is the dissolution of the big corporation, and its being replaced by a *web* of connections among individuals and small organisations. However, our model may indeed point out one reason for such institutional change.

1.2 Outline

In Section 2 the basic model is presented and some miscellaneous results are derived. In Section 3 we derive our main results. Section 4 provides a discussion about what lessons may be learned from the model and Section 5 is a conclusion.

2. The model

We will consider an overlapping-generations model with a unit measure of workers/consumers born in each period. The workers/consumers all live for two periods, and the model is deterministic. We will characterise the steady state of the model and the mode of the entire analysis will be comparative statics on this steady state. Explicit in the model is one goods-producing sector producing a homogeneous good with skilled labour and a technology. The output, y, of this sector will serve as the numeraire.

[5] *For models of career concerns, see e.g. Gibbons and Murphy (1992); for a career model close in spirit to this one, see Andersson (2000). Frank and Cook (1995) have argued that career concerns and struggles for relative positions have become more important recently; among the reasons suggested, some are directly related to technological change.*

2.1 Production technology

The productive sector consists of a set of firms, $i \in I$, each employing a set of workers l_i. Workers are characterised by their education, e, and the amount of on-the-job training, s, they have received. The technology requires that each worker goes through a period of introduction and on-the-job training before he can concentrate fully on production. We take the length of this period as exogenous, while the degree to which workers are trained is traded off against directly productive work. For simplicity, we assume that the time required for training coincides with the first period of a workers life, and that the rest of his tenure constitutes the second period; this however, is only a normalisation: by re-scaling second-period production, we could in effect allow for the second period to be longer.

The time spent working per unit of calendar time – e.g. hours worked per day – during the first period is $h_1 + s$ (the first part constituting work in production and the second on-the-job training), while the corresponding second-period input is h_2. The final determinant of production is a parameter, θ, indexing the sate of the technology. In each period, output is $f(h, e, s; \theta)$. The output of a worker over his period of employment is

$$(1) \quad f(h_1, e, 0; \theta) + f(h_2, e, s; \theta),$$

where the cost of providing on-the-job training s is the output foregone. We assume that f is increasing in $(h, e, s; \theta)$, and that for $s = 0$, f is independent of e and θ. That is, before the worker has obtained on-the-job training, he can only perform basic tasks that do not utilise his education or new technologies; this is essentially a normalisation – the results are driven by the complementarities.

Further, we assume that there are constant returns to the number of workers, and we denote by w_1 and w_2 the wages paid to the workers in the first and second periods. The price of output, y, is one, and the profit of firm i is thus

$$(2) \quad \pi_i = l_i \cdot \{ f(h_1, e, 0; \theta) - w_1 + f(h_2, e, s; \theta) - w_2 \} .$$

We assume that f is twice continuously differentiable. For our comparative-statics analysis below, the following complementarity assumption – phrased in terms of supermodularity – is key. A function is *supermodular* in a set of variables if all cross partial derivatives are non-negative; i.e., if the marginal returns to each of the variables is increasing in each one of the other variables. This is the standard production-function notion of complementarity.

Assumption 1. Per-worker production, f, is supermodular in $(h, e, s; \theta)$.

We wish to stress that this assumption is extremely weak; f being supermodular in, e.g., (e, s) means that the marginal product of on-the-job training is non-decreasing in education. We will also assume that the problem solved is concave:

Assumption 2. Per-worker production, f, is strictly concave in $(h, e, s; \theta)$.

Obviously, this implies that profits are concave in $(h_1, h_2, e, s; \theta)$.

2.2 Preferences

All workers have a common utility function over consumption, leisure, and education. Preferences are homothetic in consumption, $c = (c_1, c_2)$, in the two periods, and the workers aggregate consumption over periods by a CES intertemporal utility function,

$$v(c) = (c_1^\gamma + c_2^\gamma)^{\sigma/\gamma}\,. \tag{3}$$

Thus, we do not impose time separability, but instead impose homogeneity. The elasticity of marginal utility of wealth with respect to proportional changes in consumption is σ. For $\gamma < 1$ and $0 \leq \sigma \leq 1$, v is strictly concave with respect to all other changes in income; we assume that these inequalities are satisfied. Note that v converges to the function $v^* = (\min_{t\in\{1,2\}} c_t)^\sigma$ as $\gamma \to -\infty$. There are two reasons for our choice of v; first, we find intertemporal separability unappealing, and, second, we get an index, σ, for the marginal utility of income of colinear income streams.[6]

The disutility of working is a convex function $\psi(\cdot)$ of the time spent at work, and ψ is aggregated linearly. Hence, workers are averse to variations in work time. Workers obtain their education prior to entering the labour market (at the beginning of the first period); the disutility of acquiring education e is e, and this disutility enters additively. Their life-time utility given a consumption-employment history $(c, h) \equiv ((c_1, c_2), (h_1, h_2))$ and given (s, e) is

$$U(c,h,e) = (c_1^\gamma + c_2^\gamma)^{\sigma/\gamma} - \psi(h_1 + s) - \psi(h_2) - e. \tag{4}$$

Our imposing additive separability is somewhat restrictive but, arguably, justified by the cross-effects' likely being small and by our working with a more general specification of utility of income.

2.3 The credit market

We assume that a competitive credit market exists by means of which workers can smooth consumption. We also assume however, that such a market is pervaded by transactions-cost problems due to e.g. moral hazard, enforcement problems, or costs of writing down contracts. These transactions costs are assumed to translate into a proportional cost of handling loans so that there is an interest-rate premium, $\rho > 0$, on borrowing. With no discounting, it is obvious that the unique configuration of interest rates consistent with competitive equilibrium is ρ on borrowing and zero on lending. Albeit simple, our conception of the credit market is arguably quite realistic, as is the basic result – an interest rate premium for workers.

Granted that workers borrow something in the first period (for which case we develop the notation in the next few paragraphs), the workers solve the following problem given wages $w = (w_1, w_2)$ and employment conditions (h, e),

[6] *It also highlights a fact that seems rarely noted, namely that the coincidence of aversion to income fluctuations and decreasing marginal utility of income can be upset by a rather simple departure from time separability.*

(5) $V(w;h,s,e) \quad = \max_c (c_1^\gamma + c_2^\gamma)^{\sigma/\gamma}$
$- \psi(h_1+s) - \psi(h_2) - e,$
s.t. $\quad c_1 + c_2/(1+\rho) = w_1 + w_2/(1+\rho),$

$V(\cdot)$ being the indirect utility function. Conditional on (h, s, e), the problem reduces to maximising utility of income; this procedure defines the indirect utility of income: $v(w) = \max_c u(c)$ s.t. the budget constraint. Given an interest rate $\rho > 0$ on borrowing and zero on lending it follows immediately from the workers' objective function that the consumption path is *non-decreasing*, $c_1 \leq c_2$, precisely if $w_1 \leq w_2$; it is further immediate from homotheticity that workers will borrow in the first period if and only if $w_2/w_1 > a$ for some $a \geq 1$ (see figure 1 for an illustration).

Indirect utility of income, $v(w)$, is a concave function of w for *any* income stream (i.e., also for income streams for which the worker sometimes is a saver). Letting c^i be the consumption implied by income w^i, this is seen from

$$v(\beta w^1 + (1-\beta)w^2) \geq u(\beta c^1 + (1-\beta)c^2) \geq \beta u(c^1) + (1-\beta)u(c^2) = \beta v(w^1) + (1-\beta)v(w^2);$$

the first inequality follows from optimality and the second from $u(c)$ being concave in c. However, for colinear income streams (i.e., $w^2 = \text{constant} \cdot w^1$) and for $\sigma = 1$, the homogeneity of u implies that both inequalities are equalities.

2.4 Training

We will assume that on-the-job training obtained at one firm is *completely general* in the sense that once obtained, it is equally valuable to another employer if the worker joined her. This assumption is a useful approximation of the plausible case where another employer would enjoy a considerable fraction of the benefits.[7]

[7] *Similar assumptions are at work in, e.g., parts of the literature on internal labour markets; see e.g. Gibbons and Waldman (1999).*

The assumption of general on-the-job training, together with the assumption that workers cannot commit their labour for the long term, puts the worker in a situation akin to that facing an entrepreneur trying to finance a project whose returns depend critically on the entrepreneur's participation through specific human capital. Under such circumstances, it has been shown by Hart and Moore (1994) that there are positive net-present-value projects that will not be financed. The same forces are at work in our model, but in our environment distortions of contracts rather than complete failure results.

2.5 Contracts and incentive compatibility

Firms may offer workers long-term contracts, and they are assumed to be able to commit to honouring such contracts. Workers, on the other hand, cannot commit to long-term contracts, the reason being that the courts do not enforce them. Work hours, h, and education, e, are contractible, and on-the-job training, s, is observable but not contractible. s is assumed to be observable *ex ante* by a worker entering a firm, preventing the firm's fooling the worker; this may seem strong, but it follows naturally from training being general: if the worker finds at any point that training is inadequate, he can change employers.

To simplify expressions down the way, we denote the discount factor for a borrower $\delta = 1/(1+\rho) < 1$. Using this, a worker's total discounted income is $W_\delta = w_1 + \delta w_2$ if he is a net borrower in the first period – the case for which we develop notation – and his indirect utility function then takes the form (abusing notation a bit by replacing (w_1, w_2) by $W_\delta = w_1 + \delta w_2$ in the indirect utility functions)

(6) $V(W_\delta, h, s, e) = v(w_1 + \delta w_2)$
$- \psi(h_1+s) - \psi(h_2) - e.$

The firms maximise profits as defined by (2), and they bid competitively for workers. However, since we have assumed on-the-job training to be general, there is a potential for opportunistic behaviour by firms. If, more precisely, a worker were less profitable during the introductory period than during the rest of his tenure, there would be nothing preventing firms' only hiring trained workers. Since, further, opportunistic firms would be able to over-bid firms actually training workers, it is clear that a situation where per-worker flows of profits are larger in the second period cannot be an equilibrium; neither can the opposite situation. Equilibrium employment conditions must thus satisfy the additional constraint that

$$(7)\qquad f(h_1, e, 0; \theta) - w_1 = f(h_2, e, s; \theta) - w_2,$$

and hence the problem solved by each firm is to maximise π over (l, e, h_1, h_2, s, w_1, w_2) subject to (7) and the constraint that the solution be immune to firms' trying to steal each other's workers in an *optimal* fashion: $h_2 \in \arg\max\, v(w_1 + \delta f(h_2, e, s; \theta)) - \psi(h_2)$. However, this constraint is easily seen to be satisfied automatically since h_2 does not affect first-period profits; the objects linking the two periods, e and s, are fixed in the second period. Note that because of competition, a firm training workers too little would have to increase first-period wages correspondingly, and that would not be optimal.

2.6 Profits and equilibrium

Firms are assumed to bid competitively for workers, and this combined with constant returns to scale implies that profits are zero in equilibrium. Furthermore, the two conditions that profits be zero and that profits be equal in the two periods directly imply that

$$(8)\qquad w_1 = f(h_1, e, 0; \theta), \quad w_2 = f(h_2, e, s; \theta);$$

i.e., that the workers are in effect residual claimants of the surplus in each period. The objective function of the productive sector is thus the utility of h, s, e, and discounted wages or, equivalently, discounted *per-worker* revenues; this defines $W_\delta(h_1, h_2, e, s, \theta)$ in the indirect utility function $V(W_\delta, h, e)$ of expression (6), (and similarly for a non-barrower).

Better technologies correspond to larger values of θ, and the technology evolves for exogenous reasons. A direct consequence of this combined with (6) is that every new technology is adopted. Note that this is not immediately obvious given only the original optimisation problem faced by firms, since better technologies make the incentive constraint more severe.

3. Analysis

It will be helpful to specify the first-best solution; i.e., the solution that would obtain in the absence of the firms' incentive constraints and in the presence of a perfect credit market. If there was a perfect credit market, the intertemporal distribution of wages would not matter, and the effective objective of the productive sector would be the utility of the non-discounted per-worker revenues, $R = f(h_1, e, 0; \theta) + f(h_2, e, s; \theta)$. If there were no incentive constraints, on the other hand, firms would not be constrained to break even on a worker each period, and firms would be willing to pay a constant wage over the whole tenure of a worker; again, the objective would be to maximise R. Thus, the distortions that will be manifest below depend on the *combination* of the incentive constraint on firms' wage payments and the imperfect credit market.

When there are incentives to distort the wage profile, the interest-rate premium will remove the actual problem from the first-best problem, and since for first-best h, $f(h_1^*, e, 0; \theta) < f(h_2^*, e, s, \theta)$ (because of supermodularity), incentive compatibility *always* provides a reason for distorting the wage profile. If the workers are borrowers in the first period, the objective actually maximised is (6); if not, the workers are in effect quantity-constrained.[8]

Proposition 1. The incentive constraint has the following effects (in addition to the direct resource cost of borrowing):

i) h_1 is distorted upwards, and h_2 is distorted downwards,
ii) s and e are distorted downwards.

[8] *We remind the reader that – due to the interest-rate premium on borrowing and homothetic preferences – the worker will not borrow until* $w_2/w_1 > a$ *for some* $a \geq 1$.

Proof. Immediate from the first-order conditions for the two cases (with and without borrowing). *Q.E.D.*

The proposition says that in order to shift payments toward the first period while keeping the incentive compatibility constraint satisfied, the choice variables are distorted.

3.1 Remarks

There are several things to note about this result. The amount of work in production in the beginning of the workers' tenure, h_1, is distorted upwards *in the absence of career concerns*. This is noteworthy since it casts doubt on the view that career concerns do good by counteracting tendencies to work too little because of e.g. taxes and moral hazard. It thus lends some support to the view that (skilled) workers actually work too much, in particular during the early parts of their tenure. The obvious qualification of this observation is that the on-the-job-training part of first-period effort distorted downwards.

It is important to realise that if workers are strongly averse to income fluctuations (γ is small) and if the interest rate is high, w_1 will be close to w_2 even if this is costly in terms of incentive compatibility. The empirical manifestations of the constraint will then be in work hours and training, not in wages; such a case seems quite consistent with casual empiricism.

Note also the implications of the distortion of work hours for *incomes*. The additional dispersion of both wages and work hours for skilled workers will, by itself, increase their income, since income is the only means of compensating the distortion.

3.2 Comparative statics

We will prove our comparative-statics results under the condition that σ not be too small; i.e., that the marginal utility of income not decrease too quickly. Although our mode of analysis requires this assumption, it is clear that our key results of Proposition 4 and Claim 5 below are likely to hold under significantly weaker conditions.

Claim 2. There is $\bar{\sigma} < 1$ such that for $\bar{\sigma} \leq \sigma \leq 1$, indirect utility $V(\cdot)$ is supermodular in $(-h_1, h_2, e, s; \theta)$.

Proof. The proof is made for the case where the worker is a borrower, a similar argument applies when he is quantity-constrained. Recall from (8) how wages depend on choice variables; the cross-partials of $V = v(W_\delta(h_1, h_2, e, s, \theta)) - \psi(h_1 + s) - \psi(h_2) - e$ with respect to $(-h_1, h_2, e, s; \theta)$, letting $x_1, x_2 \in \{-h_1, h_2, e\ s; \theta\}$, $x_1 \neq x_2$, all take the form

$$(9) \quad \frac{\partial^2 V}{\partial x_1 \partial x_2} = \frac{dv}{dW_\delta}\frac{\partial^2 W_\delta}{\partial x_1 \partial x_2} + \frac{d^2 v}{dW_\delta^2}\frac{\partial W_\delta}{\partial x_1}\frac{\partial W_\delta}{\partial x_2},$$

except for the cross-derivative with respect to s and h_1 which has the additional term $\psi''(h_1 + s) > 0$ (since the derivative is with respect to $-h_1$). All cross-partials of W_δ involving h_1 are zero (f is independent of e and θ for $s = 0$ by construction), and hence all cross-partials of $V(\cdot)$ involving $-h_1$ are non-negative; the other ones are positive (due to the supermodularity of f) unless $\partial^2 v/\partial W_\delta^2$ is too negative, which it is not for σ close enough to 1. *Q.E.D.*

We now immediately have a characterisation of comparative-statics.

Proposition 3. $(-h_1, h_2, e, s)$, are non-decreasing in θ.

Proof. This follows from the well known fact that for a concave maximization problem with all cross-derivatives non-negative, an increase in marginal products by a parameter θ induces only positive feedbacks. *Q.E.D.*[9]

3.3 The intertemporal wage distortion

We are now in a position to prove that the intertemporal wage distortion is aggravated – in the sense that interest payments increase as a proportion of incomes – as productivity improves. Since intertemporal preferences are homothetic (and since the interest rate is assumed

[9] *In a previous version, we performed the analysis by means of "monotone comparative statics" in the sense of Milgrom and Shannon (1994). In that case the proposition follows from supermodularity only by a theorem from Topkis (1978).*

to be constant), a worker will increase his borrowing proportionally more than his consumption if and only if w_2/w_1 increases (if he is a borrower from the outset; otherwise he will stay put not borrowing until a switch-point for w_2/w_1 where he starts borrowing a positive amount). Consumption increases on a ray from the origin – see figure 1 – with marginal rate of substitution equal to $1 + \rho = 1/\delta$ (and lies below the endowment point for a borrower); if income stays on the same ray, interest payments increase proportionally; if w_2/w_1 increases, interest payments increase more than proportionally. This is also the condition under which total interest payments increase as a proportion of total income.

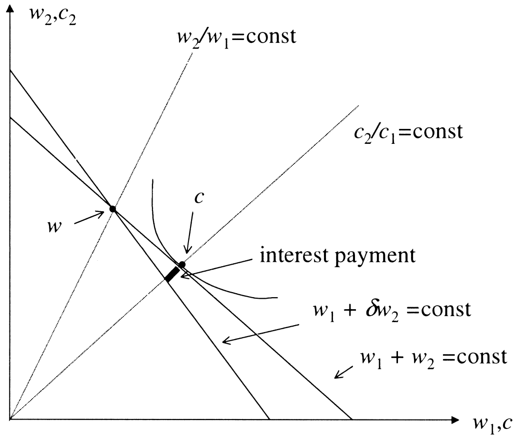

Figure 1. The endowment and the consumption bundle.

Proposition 4. Total effective wages paid to a worker, $w_1 + \delta w_2$, are increasing in θ and the intertemporal wage distortion is aggravated with increasing θ.

Proof. Again, a similar proof applies if the worker does not borrow. For notational simplicity, let $f_1 = f(h_1, e, 0; \theta)$ denote first-period output and similarly for f_2. For the first part we have two cases: (i) $h_1 + s$ decreases with θ. The first-order condition with respect to h_1 is $v' \cdot \partial f_1/\partial h - \psi'(h_1 + s) = 0$. The disutility is decreasing and the derivative of f is increasing by the concavity of f and f_1's independence of (h_2, e, s); this necessitates that v' be decreasing, implying that the effective wage, $W_\delta = w_1 + \delta w_2$, must be increasing. (ii) $h_1 + s$ increases with θ. Then, all disutility components of the utility function are increasing implying that the effective wage must increase (since utility is non-decreasing in θ). Note that wages paid, $w_1 + w_2$, must be increasing too since effective wages are increasing and we know that $w_2 = f(h_2, e, s; \theta)$ is unambiguously increasing. For the second part, note that the change of w_2/w_1 is

$$d\left(\frac{w_2}{w_1}\right) = \frac{w_1 \cdot dw_2 - w_2 \cdot dw_1}{w_1^2}$$
$$= \frac{w_2}{w_1}\left(\frac{dw_2}{w_2} - \frac{dw_1}{w_1}\right),$$

and consider this evolution for $w_2 = f_2$ and $w_1 = f_1$:

$$-\frac{\partial f_1/\partial h}{f_1}dh_1 + \frac{\partial f_2/\partial h}{f_2}dh_2 + \frac{\partial f_2/\partial e}{f_2}de$$
$$+\frac{\partial f_2/\partial s}{f_2}ds + \frac{\partial f_2/\partial \theta}{f_2}d\theta.$$

This is unambiguously positive since $dh_1 \leq 0$. *Q.E.D.*

Proposition 4 makes clear that workers will indeed be first-period borrowers at some point as θ increases, and the comparative statics of the wage distortion are *a fortiori* true (weakly) up to that point too.

3.4 Interpretations

Claim 5. The conclusions of Proposition 4 remain even if the direct productivity gain is arbitrarily small.

Proof. Nothing depends on the magnitude the direct effect of θ on f. Moreover, the direct effect can be made arbitrarily small *relative to the cross-effects,* e.g. by adding to f a suitably decreasing term depending only on θ. *Q.E.D.*

Proposition 4 and Claim 5 make precise the way in which technological change induces behavioural changes that, in turn, aggravate the incentive problem. The important lesson is that wages grow more distorted not because the technology grows more productive *per se*, but because it interacts with behaviour in a way that, on balance, requires workers to be compensated.

One may wonder if the distortions established in Proposition 1 are mitigated in that h_1 is non-increasing, and h_2 non-decreasing. These reactions are, however, optimal responses to the fact that work hours grow more valuable while, nevertheless, decreasing marginal utility of income and increasing marginal disutility of working make an hour more expensive; h_2 being made relatively more valuable explains the pattern, while the distortion relative to the optimum remains.

It may be worth noting that since f is increasing in θ (by the envelope theorem) workers are necessarily better off in total (even though, as noted in the proof if Claim 5, the gain may be arbitrarily small). It is obvious that costless beneficial technological change is something of a free lunch (and a more realistic model may discuss direct costs) but it does not change the fact that distortions are made more severe, and that the economy is moved away from its "full information utility-possibility frontier": more resources are spent on smoothing consumption.

4. Discussion and elaborations

The key insight of this paper is that technological evolution can change the ground rules of the labour market in such a way that consequences show up as distortions of contracts rather than as increases in incomes. One reason to consider this important is that it indicates that the "skill bias" of technological change – which has been the focus of much work in economics – it not as simply defined as the simplest intuition suggests. In the one-sector model explored in the main text, there is obviously not a bias in the sense that different workers are affected differently since all workers are identical. There is, however, a bias in that the possibilities for workers to distribute earnings over time are affected; with imperfections in the credit market, this matters for the workers' ultimate welfare. The paper thus suggests – by pointing out a very specific example – that the skill bias of technological change is a more subtle property than is generally realised.

The welfare implications of the insight are quite clear. It is not a foregone conclusion that the potential benefits of technological change can be fully realised. If distortions are aggravated due to incentive constraints becoming tighter, the benefits will be reduced. This feature would, moreover, be more striking if there were explicit costs of improving technology rather than free-lunch improvement as in the model. Again, the example provided by the model is very specific, but, again too, we strongly believe that the broader interpretation is valid and that this insight is very important.

In terms of policy implications, the paper points out that the functioning of credit markets is important. If workers could borrow on a perfect credit market in the model, the distortions would vanish. Even if such a state of affairs is unattainable, it is clearly possible to affect the way credit markets work by means of policy interventions. The model also points to the importance of substitutes for a perfect credit market; institutions that facilitate the acquisition of human capital – e.g. public schooling and student loans – are beneficial in the model.[10] This argument is distinct from standard distributional arguments as well as from arguments stemming from governments' inability to refrain from taxing returns to education *ex post*.[11]

Finally, one may note that the model provides an instance where income taxation may be corrective rather than distortionary.[12] In this model the distortion is that firms are forced to use earning profiles as a device for protecting their investments in their workers' human capital; the social cost is due to the workers' not being able to smooth consumption costlessly. It is clear that progressive (or proportional) taxes combined with lump-sum transfers indeed would *help* in smoothing consumption and thus produce a welfare gain.

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[10] An important caveat in this regard is the forces at work in furthering globalization; if taxes will increasingly be borne by low-skill workers due to globalisation and tax competition, this is an argument against public financing of higher education; see Wildasin (2000).

[11] For a more detailed discussion of the last argument, see Anderberg and Andersson (2000).

[12] The observation that income taxation, as well as other means of taxation, may be corrective rather than distortionary has been made e.g. by Andersson (1996) in the context of job-market signalling, and by Frank and Cook (1995) in situations where individuals participate in positional races due to e.g. career concerns.

5. Conclusion

Our intentions have been, first, to point out that the indirect effects of technological change may be important – an observation we believe is generally valid and very important – and, second, to develop a specific model linking certain features of the labour market to technological change.

Our first point is simple but seems to be given conspicuously little attention. It seems that most of the discussion about technological change is made with the implicit assumption that non-tangible factors are unimportant, at least in the long run. Although we are somewhat sympathetic to such a view, we have not seen a convincing argument. Moreover, we believe that a plausible approach to this general issue is to try to understand what indirect forces *might* be at work. We also believe that the economics of information and incentives is a natural place to start.

The second part of our objective has lead us to analyse a simple equilibrium model of the labour market and our conclusions from doing so have been fairly intuitive. The incentive problem on the labour market of our model imposes costs on its workers, and in the end these costs translate into higher but more severely distorted wages; as a consequence, income distribution will be more unequal in money terms. It is notable that our model implies that workers work too hard early in their careers in the absence of career concerns; this seems to be a fact of actual labour markets – in particular high-skill labour markets – and there being several sources of it may corroborate its importance.

As we have pointed out, we think that the general issue of indirect effects of technological change is worth attention from as many different perspectives as possible. More specifically, however, we think that the paper calls for investigation of how the forces considered interact with established theories of the labour market such as career concerns and efficiency wages. We hope to address this in future work.

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Appendix

This appendix explores how the mechanisms shown work in a two-sector closed economy. The high-skill sector satisfies the assumptions made in the text; the output, y, of this sector is the numeraire. The low-skill sector produces another good z under constant returns using only low-skilled labour – i.e. labour without education. The price of z is denoted p_z. Hours worked per unit of time are normalised to one in the low-skill sector, and it is assumed that this is true for technological reasons so that it is unaffected by price changes. It may e.g. be interpreted as assuming that the production function has sharp kink at that point. Hence, the wage paid is equal to the price of output, p_z. There is free mobility between sectors at the beginning of a worker's career.

The analysis for a closed economy follows the same lines as that of the open economy except for that we have additional constraints coming from the balance equations. That is, the relative prices will be determined endogenously, and so will the employment levels.

We know from the previous section that the direct effect of technological change will be increasing wages to high-skill workers; in fact we know sightly more: from Proposition 4, both $w_1 + \delta w_2$ and $w_1 + w_2$ are increasing. We will not wee how this change plays out in the entire system.

Basic balance equations

We start by deriving the balance equations of the economy. Supply of goods y and z is

$$\text{(A.1)}\quad y = \textstyle\sum_{i\in I} l_i\{\, f(h_1, e, 0; \theta) + f(h_2, e, s; \theta)\},\quad z = 1 - \textstyle\sum_{i\in I} l_i.$$

We will introduce the following pieces of notation for the total wages paid to high-shill workers and for the fraction of workers employed by the high-skill sector,

$$\text{(A.2)}\quad W = w_1 + \delta w_2, \quad \sigma = \sum_{i\in I} l_i.$$

Demand for the two goods is, because of homothetic preferences, given by

$$\text{(A.3)}\quad y = \sigma\cdot W\cdot D_y(1,p_z) + (1-\sigma)\cdot p_z\cdot D_y(1,p_z),$$
$$z = \sigma\cdot W\cdot D_z(1,p_z) + (1-\sigma)\cdot p_z\cdot D_z(1,p_z),$$

where D_y and D_z satisfy the basic conditions for demand functions. Hence, the equilibrium conditions are given by setting demand equal to supply,

$$\text{(A.4)}\quad \sigma\cdot W\cdot D_z(1,p_z) + (1-\sigma)\cdot p_z\cdot D_z(1,p_z) = 1-\sigma,$$

$$\text{(A.5)}\quad \sigma W D_y(1,p_z) + (1-\sigma)p_z D_y(1,p_z) = \sum_{i\in I} l_i\{\alpha(f_1 - c) + (1-\alpha)f_2\}.$$

General equilibrium

By Walras' law, we know that one of the equilibrium equations above will be redundant (by just plugging in the wages, we have already accounted for the zero-profit condition), and we will work with (A.4). The other condition for general equilibrium is that the labour market be in equilibrium also with respect to the worker's choice of education; i.e., a worker must be indifferent between working in the two sectors. With obvious notation,

$$\text{(A.6)}\quad V(W;p) - \psi_1 - \psi_2 - e = 2\left(V(p_z;p) - \psi(1)\right),$$

where we remind the reader that low-skill workers have $h = 1$ and earn p_z.

Comparative statics

The equilibrium conditions of the economy can now be expressed as the simultaneous solution of the equilibrium condition for the labour market, (A.6), and the equilibrium condition for the product market, (A.4), rewritten slightly,

$$\text{(A.7)}\quad V(W;p) - \psi_1 - \psi_2 - e - 2[V(p_z,p) - \psi(1)] = 0,$$

$$\text{(A.8)}\quad \frac{\sigma}{1-\sigma}W - \frac{1 - p_z D_z}{D_z} = 0.$$

This leaves us with two equations for the two unknowns σ and p_z, the comparative statics of which may be assessed by calculus.

Proposition A.1. The increasing wage payments to high-skill workers leads to an increase in the price of low-skill sector output (and hence the low-skill sector wage). Moreover, if the two goods are strongly complementary, employment will shift towards the low-skill sector; while if the goods are easily substitutable, employment will shift towards the high-skill sector.

The second part of the conclusion is less clear-cut than one would wish. We have not found a sensible more precise statement about where the cut-off between the two cases may be found.

Proof. Let $\lambda = \sigma/(1-\sigma)$ be the relation between the sector employment shares and let $V_H = V(W; p)$ be the utility of income for high-skill sector workers and correspondingly $V_L = V(w_L; p)$ with $w_L = p_z$ for low-skill sector workers. Differentiating (A.7) and (A.8) we get

$$\begin{bmatrix} 0 & \partial V_H/\partial p_z - 2[\partial V_L/\partial w_L + \partial V_L/\partial p_z] \\ W & 1 + \partial D_z/\partial p_z \cdot 1/D_z^2 \end{bmatrix} \cdot \begin{bmatrix} \partial\lambda/\partial W \\ \partial p_z/\partial W \end{bmatrix} = \begin{bmatrix} -\partial V_H/\partial W \\ -\lambda \end{bmatrix}$$

The determinant is $\Delta = -W\partial V_H/\partial p_z - 2[\partial V_L/\partial w_L + \partial V_L/\partial p_z]\} > 0$ since the inner brackets is the total derivative of low-skill workers' utility with respect to p_z which is their wage, and hence positive.

Inverting we get

$$\begin{bmatrix} \partial\lambda/\partial W \\ \partial p_z/\partial W \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} 1 + \partial D_z/\partial p_z \cdot 1/D_z^2 & -(\partial V_H/\partial p_z - 2[\partial V_L/\partial w_1 + \partial V_L/\partial p_z]) \\ -W & 0 \end{bmatrix} \cdot \begin{bmatrix} -\partial V_H/\partial W \\ -\lambda \end{bmatrix}$$

where we immediately see that the second row is positive, and hence p_z is increasing. To assess the first row, rewrite the upper left element of the matrix as

$$\frac{1}{p_z D_z} \left(p_z D_z + p_z/D_z \cdot \partial D_z/\partial p_z \right),$$

where $p_z D_z$ is the expenditure and the second term is the price elasticity of demand. If the elasticity is small, the first row is negative. If the elasticity is large enough (and it can be arbitrarily large), the upper left term will be negative and large in magnitude, and the first row will be positive. *Q.E.D.*