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TECHNOLOGICAL PROGRESS, JOB CREATION AND JOB DESTRUCTION

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ABSTRACT

We generalize apparently contradictory results in the literature about the effect of exogenous technological progress on unemployment. We assume that new technology can be adopted either through creative job destruction or through on-the-job implementation at a cost. We show that there is a critical level of implementation cost where the effect of growth on employment switches from positive to negative at higher costs. In extensions of the model we show that gross job reallocation can increase at faster growth with no clear-cut effects on aggregate employment.

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Introduction

How does technological progress affect the equilibrium number of jobs? Workers often fear the introduction of new machines that embody new technology because they believe that the machines would destroy their jobs. Economic history is full of examples where old jobs are replaced by new ones that use more technologically-advanced machines. New technology destroys jobs but it also creates new ones. John F. Kennedy was referring to this process as a vehicle for advancement when he said, "if men have the talent to invent new machines that put men out of work, they have the talent to put those men back to work" (quoted in The Economist, February 11, 1995, p.23). In this paper we look at equilibrium outcomes for job creation and job destruction when new technology is embodied in new machines.

We assume that the "talent to invent new machines" is exogenous. The productivity of new machines grows at fixed exponential rate because of the embodiment of new technology. The conventional view (summarised in The Economist, February 11, 1995) is that when new technology arrives, old jobs are destroyed with beneficial effects on labor productivity and new ones are created because of more final demand, due to the higher incomes. In our model, new jobs are created because with higher productivity, the demand for labor at given wages is higher.

So our reasoning is not far from the conventional one: but merely postulating that new jobs are created where old ones are destroyed does not necessarily imply that the economy will settle at a higher or the same level of employment. What is needed to answer that question is an equilibrium model,
with job creation and job destruction determined within the same optimizing framework, and with the equilibrium number of jobs determined by their interaction. The aim of this paper is to offer such a model. In this model, we try to resolve an apparent inconsistency that is found in the literature on the effects of growth on unemployment, with results at one extreme arguing that faster growth reduces unemployment (Pissarides, 1990, chapter 2) and at the other extreme that it increases unemployment (Aghion and Howitt, 1994).

In the model that we study new jobs embody the most advanced known technology.[1] Creation commits the firm to that technology, unless the firm decides to update a job's technology by bearing some fixed `implementation cost'. We think of the implementation cost as an internal adjustment cost, not unlike the internal adjustment costs assumed in the literature on investment. In our model, the implementation cost may also include the cost of training the worker to use the new machine, though training has to be specific to the job. We assume that the implementation cost is fixed and paid once for all.

We show that firms will follow different job creation and job destruction policies depending on the size of their implementation costs, and overall market equilibrium will also be different. If the cost of implementing new technology is high compared with job creation costs, the firm may keep the job open for as long as it yields some positive profit and then destroy it. Firms with smaller implementation costs may update their technology on the job, without job destruction. Eventually, every firm has to either implement the new technology or destroy its job, because the new jobs created elsewhere drive out old jobs by bidding away their workers.

When creating a job, a firm correctly anticipates the length of time the bidding process will take to make the job obsolete. Faster technological progress speeds up the bidding process but also increases the job's productivity. The reason it might lead to less job creation in equilibrium is that when jobs have a shorter life, employers may not be able to recoup their creation or implementation costs before obsolescence at the same rate of market tightness as before. We examine the conditions under which equilibrium employment is higher at faster rates of technological progress and the conditions under which it is lower.

The results found in the literature on growth and unemployment can now be interpreted as extreme cases of our more general model. In the case recently examined by Aghion and Howitt (1994),[2] the firm never finds it optimal to implement the new technology, so the useful life of a job is shorter when the rate of technological progress is higher. Aghion and Howitt look at the implications for the equilibrium unemployment rate in the long run and find an ambiguous relationship, though as we show later, if one concentrates only on the implications of what they call the "creative destruction" of jobs, faster growth unambiguously leads to higher unemployment.

In contrast, at the other extreme of the continuous updating of technology, which parallels the introduction of new technology in the Solow growth model, job creation is positively affected by technological progress because of the capitalization effect of growth on expected profits. In this case, as shown in Pissarides (1990, chapter 2), equilibrium unemployment is lower at higher rate of technological progress.

Interpreting now the case of the continuous updating of technology as the extreme of zero implementation cost, we are able to show that whether faster technological growth raises or lowers equilibrium unemployment depends on the size of the implementation costs. There is a unique implementation cost where the effect of growth on unemployment switches from negative to positive as costs rise. The effect of growth on job creation may be negative even when firms implement the new technology on the job, provided the implementation cost is sufficiently high.

Following the description of our basic model, we generalize our framework to examine two issues. First, the implications of match-specific heterogeneity and second, a problem that has been neglected in this literature, factor mobility.

We show that when there is job-specific heterogeneity, firms at the lower end of the productivity spectrum will be adopting new technology through creative destruction, whereas firms at the top end will be implementing the new technology. High job-specific productivity is a valuable resource that the firm tries to preserve by not destroying the job. The new result concerning growth is that when there is faster growth, and provided implementation costs are not too high, more firms will be destroying jobs to adopt the new technology but those that adopt the new technology through implementation will be creating more jobs. So we are likely to observe simultaneously higher job creation and higher job destruction, depending on the size of the job-specific productivity.

In order to study the implications of factor mobility, we assume an economy with two sectors at each extreme of the implementation cost range, one with sufficiently high costs and creative destruction and one with zero implementation costs and continuous updating of technology. We also assume costless mobility of both labor and capital between the sectors.[3]

We show that with factor mobility, higher productivity growth leads to a shift of resources from the sector with the high implementation costs to the one with the zero costs. Thus, even with only exogenous destruction rates in the sector with the zero implementation costs, it is possible for the economy's overall destruction rate to go down at higher productivity growth, because of the changing composition of employment. Job creation rates can also be higher overall, despite the lower creation rates in the creative destruction sector.

Section 1 gives the notation used throughout the paper and some key assumptions. Section 2 analyzes the case of the adoption of new technology through job destruction. The more general case of finite implementation cost is analyzed in section 3. Section 4 introduces the job-specific heterogeneity and section 5 describes the equilibrium with mobility in the two-sector economy.

1. Notation and Assumptions

Firms in our model are small and constrained to employ one worker each[4]. A firm without a worker advertises a job vacancy for a cost $p(t)c$ and waits for the arrival of a worker. When a worker arrives the firm creates a job by bearing creation cost $p(t)K$ and choosing a technology amongst the known ones. Profit maximization leads to the choice of the most advanced known technology. Once the job is created, however, job productivity does not change, unless the firm implements new technology at a cost $p(t)I$.

Job creation takes place in response to profit maximization given the expected revenues and costs from new jobs. Job destruction takes place either in response to an exogenous event that arrives with frequency d or because the job has ceased to be profitable and the firm chooses to close it down. We assume perfect foresight throughout the analysis. The uncertain events, such as the arrival of the exogenous destruction shock, are governed by a Poisson law.

The most advanced known technology is on the productivity frontier where job productivities grow at the exogenous rate g. Wages in existing jobs are continually recontracted to share the net surplus from the job, taking into account the worker's alternative of quitting the job to search for a new one. Since wages in new jobs grow with productivity, wages in existing jobs must also grow with it even if the own job productivity is constant, to reflect the fact that the worker's outside option grows. Therefore, there comes a time when a firm with a job created in the past has to either pay the implementation cost to move back on the productivity frontier or destroy the job. The firm has the choice of which one to pursue, and this choice is one of the new features of our model.

Labor's opportunity cost, job-creation costs and implementation costs grow at the exogenous rate g. These assumptions are made to ensure the existence of a steady state with balanced growth and are not essential in the existence of endogenous job destruction or technology implementation.

Firms that open up vacancies participate in a matching game governed by a matching function $m(v,u)$, where $m()$ is increasing concave and homogeneous of degree one in aggregate job vacancies, v, and unemployment, u, both expressed in terms of the fixed labour force. The wage is determined after the worker arrives and is assumed to share the capital value of a match in fixed proportions between the worker and the employer. The worker's share is denoted ß.[5]

More analytically our notation is as follows:

t = current time

$V(t)$ = value of a job vacancy at date t

$J(t,a)$ = value of an existing job of age a created at time t

$U(t)$ = value of unemployed search at date t

$W(t,a)$ = value of employment in a job of age a created at time t

$p(t)x$ = value of labor product on the technology frontier at date t

$p(t)b$ = worker's opportunity cost of employment at date t

$p(t)I$ = cost of implementing new technology at date t

$p(t)c$ = cost of posting a vacancy at date t

$p(t)K$ = cost of creating a new job at date t

d = exogenous job destruction rate

g = rate of productivity growth, defined by

$$g = \frac{\dot{p}(t)}{p(t)} \tag{1}$$

r = rate of discount

T = age at which a job is either destroyed as obsolete or new technology is implemented

Firms make job creation and job destruction decisions so as to maximize the expected present value of future profits. Positive gains from trade and finite present values require $b<x$ and r+d>g respectively. Both inequalities are maintained assumptions in the sequel. All parameters not indexed by t are independent of time.

2. Job Destruction through Obsolescence

A firm with a new vacancy participates in matching for a cost $p(t)c$ per period and must pay the job creation cost $p(t)K$ as a lump sum when matched with a worker. Hence the expected return for each vacancy satisfies the Bellman equation

$$rV(t) = \frac{m(v,u)}{v}[J(t,0) - V(t) - p(t)K] - p(t)c + \dot{V}. \tag{2}$$

In this equation, with total matchings given by $m(v,u)$, the rate at which each vacancy is matched to a worker is $m(v,u)/v$. We define market tightness by ? = v/u, and make use of the homogeneity of the matching function to write the arrival rate of workers as $m(?,1)/?$.

In equilibrium, vacancies enter the market until all rents from new job creation are exhausted, i.e. $V(t) = 0$ for all t. This condition and equation (2) imply that market tightness at time t satisfies

$$\frac{?c}{m(?,1)} \;\%\; K \;\text{'}\; \frac{J(t,0)}{p(t)}. \tag{3}$$

We first study the case where the implementation cost is so high that the firm waits for obsolescence rather than ever implement new technology. The value to an employer of a job of age a created at date t solves the Bellman equation

$$rJ(\text{t},a) \;\text{'}\; \max6p(\text{t})x \;\&\; w(\text{t},a) \;\&\; \text{d}J(\text{t},a) \;\%\; J_a(\text{t},a), 0› \tag{4}$$

where the right side takes account of the fact that the job is destroyed once the return on its value to the employer falls below zero. Analogously, the value to a worker of employment in such a job solves

$$rW(\text{t},a) \;\text{'}\; \max6w(\text{t},a) \;\&\; \text{d}[W(\text{t},a) \;\&\; U(\text{t}\%a)] \;\%\; W_a(\text{t},a), U(\text{t}\%a)›. \tag{5}$$

The value of unemployment given employment in such a job solves

$$rU(\text{t}\%a) \;\text{'}\; p(\text{t}\%a)b \;\%\; m(?,1)[W(\text{t}\%a,0) \;\&\; U(\text{t}\%a)] \;\%\; U_a(\text{t}\%a) \tag{6}$$

where $m(?,1)$ is the rate at which jobs arrive to unemployed workers and $t = \text{t}+a$ is the current date.

The worker and employer share the surplus match value in fixed proportions, i.e. with the returns from a vacancy equal to zero in equilibrium,

$$\text{ß}J(\text{t},a) \;\text{'}\; (1\&\text{ß})[W(\text{t},a) \;\&\; U(\text{t}\%a)]. \tag{7}$$

Then, equations (4)-(7) imply that the wage is

$$\begin{aligned} w(\tau,a) &= \beta p(\tau)x + (1-\beta)\big[p(\tau+a)b + m(\theta,1)[W(\tau,a) - U(\tau+a)]\big] \\ &= \beta[p(\tau)x + m(\theta,1)J(\tau+a,0)] + (1-\beta)p(\tau+a)b. \end{aligned} \tag{8}$$

The optimally chosen age of destruction T maximizes the value of a job, which is defined by the following functional equation by virtue of equation (4):

$$\begin{aligned} J(\tau,a) &= \max_T \left\{ \int_a^T [p(\tau)x - w(\tau,s)]e^{-(r+\delta)(s-a)}ds \right\} \\ &= \max_T \left\{ \int_a^T \big[(1-\beta)[p(\tau)x - p(\tau+a)b] - \beta m(\theta,1)J(\tau+s,0)\big]e^{-(r+\delta)(s-a)}ds \right\}. \end{aligned} \tag{9}$$

To obtain a solution to the functional equation (9), we conjecture that the value of a new job is proportional to productivity on the technology frontier, $p(t)$, i.e. $J(t,0)=p(t)J$. Substituting this expression into equation (9) when a=0 confirms the conjecture and gives J as the unique solution to

$$J = \max_T \left\{ \int_0^T [(1-\beta)(x - be^{\gamma t}) - \beta m(\theta,1)Je^{\gamma t}]e^{-(r+\delta)t}dt \right\}. \tag{10}$$

Market tightness θ solves

$$\frac{c\theta}{m(\theta,1)} + K = J \tag{11}$$

by virtue of equation (3).

Now, substituting $p(t+a)J$ for $J(t+a)$ in equation (8) gives the wage equation,

$$w(t,a) = p(t)\left[\beta x + [(1-\beta)b + \beta m(\theta,1)J]e^{ga}\right]. \qquad (12)$$

Wages in existing jobs (created at some past date t) grow even in the absence of an exogenous opportunity cost for labor, in response to technical progress and wage growth in new jobs. Because all new vacancies pay the higher wage, the worker's outside option improves during employment, causing the wage growth independently of the paths of own productivity and non-employment returns. This endogenous wage growth is the key to the endogenous job destruction or technology implementation in our model, in contrast to earlier studies that assumed exogenous wage growth.

An *equilibrium solution* to the model is a job value and market tightness pair (J^0,θ^0) that solves equations (10) and (11). As the relation between J and θ implied by (10) is negatively sloped while that of (11) has a positive slope, a unique solution exists. To be economically meaningful, however, the equilibrium values of both job value and market tightness must be strictly positive, which obtains in general if and only if non-employment income b, the cost of job creation K, and the worker's share parameter β are sufficiently small. This condition is assumed to be satisfied throughout the remainder of the analysis.

Faster growth shifts down the negatively sloped relation between J and θ implied by equation (10) but does not affect the positive relation implicitly defined by equation (11). Consequently, both the equilibrium values of match surplus and market tightness decline with the growth rate, i.e. $\partial J^0/\partial g < 0$ and $\partial \theta^0/\partial g < 0$. Of course, these results obtain because the wage paid in every job grows with age at a rate that increases with g.

The optimal age of job destruction through obsolescence is the solution to the problem defined on the right side of (10) and can be written as

$$[(1-\beta)b + \beta m(\theta^0,1)J^0]e^{gT^0} = (1-\beta)x. \tag{13}$$

Although the effect of growth on the age of obsolescence appears unclear from this, because J^0 and θ^0 both decrease with g, by substituting from (13) back into equation (10) and then integrating the result, we find that J^0 and T^0 are related by

$$J^0 = (1-\beta)x\left[\frac{1-e^{-(r+\delta)T^0}}{r+\delta} - e^{-gT^0}\frac{1-e^{-(r+\delta-g)T^0}}{r+\delta-g}\right]. \tag{14}$$

It follows immediately from this that $\partial J^0/\partial g < 0$ implies $\partial T^0/\partial g < 0$.

In the economy studied so far, jobs are destroyed either because they experience an exogenous job destruction shock or because they reach the age of obsolescence. Given an exogenous rate of job destruction equal to δ, the fraction of the job creation flow that survive to retirement is $\exp\{-\delta T^0\}$. Hence, the total job destruction flow, *JD*, is $\delta n + JC\exp\{-\delta T^0\}$ where n denotes the level of employment and *JC* represents the job creation flow. Job creation equal job destruction in steady state and the job creation flow is equal to the rate at which workers are matched with jobs, i.e.

$$JC = m(\theta^0,1)u = \delta n + JCe^{-\delta T^0} = JD. \tag{15}$$

Given inelastic participation, i.e. $u = 1-n$, the implied steady state unemployment rate is

$$u = \frac{\delta}{\delta + [1-e^{-\delta T^0}]m(\theta^0,1)}. \tag{16}$$

Consequently, unemployment increases with growth because both the age at obsolescence, T^0, and market tightness, θ^0, decrease with g.

3. Adoption of New Technology through Implementation

Now suppose that the firm has the option of implementing new technology at fixed cost $p(t)I$. Since the implementation cost is fixed, the firm that implements will always choose to move to the current technology frontier, i.e. if implementation takes place at t, the value of its job jumps from $J(t-a,a)$ to $J(t,0)$. Since the firm has the option of adopting the new technology through creative destruction, it follows that the "implementation horizon" must be smaller than the "destruction horizon", i.e. if the new technology is implemented at age T, then $T \leq T^0$.

A firm that follows an implementation policy creates a job of value $J(\tau,0)$ at time τ, and at time $\tau+T$ it pays implementation cost $p(\tau+T)I$ to raise the value of its job from $J(\tau,T)$ to $J(\tau+T,0)$. Hence, the Bellman equation given implementation is

$$J(\tau,0) = \max_T \left\{ \int_0^T [p(\tau)x - w(\tau,s)]e^{-(r+\delta)s}ds + e^{-(r+\delta)T}[J(\tau+T,0) - p(\tau+T)I] \right\}$$

$$= \max_T \left\{ \int_0^T \Big[(1-\beta)[p(\tau)x - p(\tau+a)b] - \beta m(\theta,1)J(\tau+s,0)\Big]e^{-(r+\delta)s}ds + e^{-(r+\delta)T}[J(\tau+T,0) - p(\tau+T)I] \right\}. \quad (17)$$

As $J(\tau+s,0) = e^{gs}p(\tau)J$, the equilibrium pair (J,θ) now solves equation (11) and

$$J = \max_T \left\{ \int_0^T \Big[(1-\beta)(x - be^{gs}) - \beta m(\theta,1)Je^{gs}\Big]e^{-(r+\delta)s}ds + e^{-(r+\delta-g)T}(J - I) \right\}. \quad (18)$$

Since again (11) has positive slope in (J,θ) space and (18) has positive slope, equilibrium is unique.

The first-order maximization condition for the implementation horizon is

$$(1-\beta)x - [(1-\beta)b + \beta m(\theta,1)J]e^{gT} = (r+\delta-g)(J - I)e^{g} \quad (19)$$

By integrating the right side of (18) and rearranging the result, we get,

$$J - I = \max_T \left\{ \frac{(1-\beta)x\dfrac{1-e^{-(r+\delta)T}}{r+\delta} - [(1-\beta)b+\beta m(?,1)J]\dfrac{1-e^{-(r+\delta-g)T}}{r+\delta-g} - I}{1-e^{-(r+\delta-g)T}} \right\}. \qquad (20)$$

By substitution from (19) into (20), we obtain the following implicit representation of the relationship between the optimal implementation horizon and the implementation cost:

$$(1-\beta)x\left[\frac{1-e^{-(r+\delta)T}}{r+\delta} - e^{-gT}\frac{1-e^{-(r+\delta-g)T}}{r+\delta-g}\right] = I. \qquad (21)$$

As the left side is increasing in T given the maintained assumption $r+\delta>g$, the implementation horizon increases with the cost, i.e. $\partial T/\partial I > 0$. Furthermore, equations (14) and (20) and $T \leq T^0$ imply that implementation is optimal if and only if $I \leq J^0$.

The nature of the optimal implementation policy is illustrated in Figure 1 (on logarithmic scale). The line AA illustrates the maximum value of a job with the best technology at time τ. All new jobs are created on that line. The line BB deducts the implementation cost I from AA. When a new job is created, say at time τ, its value starts to fall because of wage growth. When the value of the job hits BB at time $\tau+T$, it is to the firm's advantage to pay the implementation cost and move the job's value up to line AA. This process continues indefinitely until the job is destroyed by the idiosyncratic shock which occurs with frequency δ.

As the figure suggests and equation (20) implies, updating of technology becomes more frequent as implementation cost I falls . Furthermore, in the extreme, as I approaches zero, technology is updated continuously, i.e. T tends to zero as well. As I increases, technology is updated less frequently until the implementation cost is sufficiently large to push the intersection of the BB line with the value of the job on the horizontal axis, which occurs at $I = J^0$. For any larger value of the cost, implementation is never optimal and job destruction takes place at age T^0. Finally, differentiation of equation (21) yields $\partial T/\partial g < 0$, i.e. implementation is more frequent at higher rates of growth.

When all firms implement the new technology, the job destruction rate in the economy is simply the frequency of exogenous destruction δ. So the interesting question in this case concerns the effects of growth on job creation. As in the previous section, job creation depends directly on the value of a new job, i.e. equation (11) continues to hold. Because the right side of (18) can either rise or fall with the growth rate depending on parameter values, the effect of growth on the value of a new job is ambiguous in general when implementation is optimal.

At the extreme of zero cost implementation of new technology is instantaneous, T=0, and the standard Solow assumption that growth in productivity is the same for old and new jobs obtains. As a consequence, the value of a job increases with the rate of growth when implementation costs are small. To establish this fact, simply note that (20) and (21) imply

$$\lim_{I \to 0} J = \frac{(1-\beta)x - [(1-\beta)b + \beta \lim_{I \to 0} J\, m(\theta,1)]}{r + \delta - g}. \tag{22}$$

This equation and (11) require that both J and θ increase with g when I is small. In this case, growth has a pure capitalization effect which stimulates job creation. Since the job destruction rate is equal to the exogenous parameter δ, growth reduces unemployment when the cost of implementation is small.

Thus, different qualitative effects of productivity growth on job creation obtain at the two extremes, with faster growth reducing unemployment at sufficiently low implementation costs and increasing it at sufficiently high costs. It is natural to ask whether a unique critical cost exists in between, say at $I = I^*$, where the creative destruction effect just offsets the capitalization effect. The answer is yes.

Proposition: A unique implementation cost I^* exists such that $\partial J/\partial g>(<)0$ as $I<(>)I^*$.

Proof. Because (11) implies that ? depends on J but not on g directly, equation (18) and an application of the envelope theorem imply

$$sign\left\{\frac{\partial J}{\partial g}\right\} = sign\left\{1 - \frac{[(1-ß)b + ßm(?,1)J]e^{gT}}{1-ß}\frac{e^{(r+d-g)T} - 1}{(r+d-g)T}\right\}. \qquad (23)$$

Because $T \to 0$ implies that $[e^{(r+d-g)T}-1]/(r+d-g)T \to 1$, the second term in the braces tends to a number less than unity in absolute value by virtue of the first order condition (19) as $I \to 0$. Hence, $\partial J/\partial g > 0$ at $I = 0$. Similarly, the second term tends to $[e^{(r+d-g)T}-1]/(r+d-g)T > 1$ as $I \to J^0$ because $T \to T^0>0$. As a consequence, $\partial J/\partial g < 0$ at $I=J^0$. To complete the proof, we need to demonstrate that the term on the right side switches sign only once on the interval in between.

Because $[e^{(r+d-g)T} - 1]/(r+d-g)T$ increases with T and T increases with I, it is sufficient to show that the term

$$z = [(1-ß)b + ßm(?,1)J]e^{gT} \qquad (24)$$

increases with I at $I=I^*$, defined as any one of the values of cost for which the right side of (23) is zero. If this condition holds, the proposition holds in a neighborhood of every I^*. Because otherwise a contradiction arises, I^* is unique as a consequence.

By differentiating equations (20) and (21) with respect to I, we obtain,

$$\frac{\partial \ln(z)}{\partial I} = g\frac{\partial T}{\partial I} + \left[\frac{\beta}{(1-\beta)b+\beta m(\theta,1)J}\right]\frac{\partial(m(\theta,1)J)}{\partial J}\frac{\partial J}{\partial I}$$

$$= \frac{e^{gT}}{1-\beta}\frac{r+\delta-g}{1-e^{-(r+\delta-g)T}}\left[1 - \left[\frac{1-\beta}{[(1-\beta)b+\beta m(\theta,1)J]e^{gT}}\right]\frac{\beta\frac{\partial(m(\theta,1)J)}{\partial J}e^{-(r+\delta-g)T}}{r+\delta-g+\beta\frac{\partial(m(\theta,1)J)}{\partial J}}\right]. \quad (25)$$

Given that the right side of (23) is zero,

$$\frac{\partial \ln(z)}{\partial I}\Big|_{I=I^*} = \frac{(r+\delta-g)e^{gT}}{(1-\beta)(1-e^{-(r+\delta-g)T})}\left[1-\left(\frac{1-e^{-(r+\delta-g)T}}{(r+\delta-g)T}\right)\times\left(\frac{\beta\frac{\partial(m(\theta,1)J)}{\partial J}}{r+\delta-g+\beta\frac{\partial(m(\theta,1)J)}{\partial J}}\right)\right] > 0 \quad (26)$$

because both components of the product are less than unity. ~

As the job destruction rate is equal to the exogenous frequency δ when new technology is implemented, the unemployment rate is simply

$$u = \frac{\delta}{\delta + m(\theta,1)}. \quad (27)$$

Faster growth affects unemployment in this case only through its effect on market tightness, so higher productivity growth leads to more job creation and lower equilibrium unemployment for implementation costs in the rate $0 \le I < I^*$. For costs in the range $I^* < I \le J^0$, higher growth induces higher unemployment. In addition, since J^0 is lower at higher rates of growth, the highest acceptable implementation costs before the firm resorts to creative destruction, I^0, is also lower at higher growth rates. In other words, if implementation costs vary across firms, a larger fraction would engage in job destruction rather than implementation in countries with higher growth rates.

4. Match Heterogeneity

We now consider the first extension of our model, the existence of job-specific productivity differences. We assume that productivity differs across new matches because of differences in the idiosyncratic component of productivity, x. The purpose of considering this generalization is twofold. First, we show that the set of matches for which implementation is optimal decreases with the rate of technical progress, a fact that provides a second reason why the job destruction rate might increase with growth. Second, when implementation costs are low (and if matches are sufficiently heterogeneous) both the job creation flow and the job destruction flow increase with the rate of productivity growth, providing a reason for more job turnover at higher rates of growth.

As before, let $p(t)x$ denote match productivity but where x is now a random idiosyncratic component characterized by the distribution function $F(x)$. In the case of any specific match, x is realized when the worker and job meet. To avoid complications that do not affect the qualitative results that we want to establish here, we restrict the discussion to the case in which employers have all the market power, i.e. we solve the model for ß=0.

The age at destruction for a job known to have specific productivity x, denoted as $T^0(x)$ solves equation (13), which can now be written as

$$T^0(x) = \frac{1}{g}\ln\left(\frac{x}{b}\right). \tag{28}$$

Of course, $T^0(x)$ is monotone increasing in x and will take on negative values for $x \le b$. As a non-positive age of destruction implies that such a match yields no surplus at any age, no match forms in this case. But any value of the match-specific productivity parameter that yields positive surplus is acceptable. It follows from (28) that when workers receive no share of match surplus ($\beta=0$), reservation match productivity is equal to b, the opportunity cost of employment.

If implementation of new technology is optimal for a match with specific productivity x, then the implementation horizon, expressed as a function $T(x,I)$ of the match-specific productivity and implementation cost, solves

$$x\left[\frac{1-e^{-(r+\delta)T(x,I)}}{r+\delta} - e^{-gT(x,I)}\frac{1-e^{-(r+\delta-g)T(x,I)}}{r+\delta-g}\right] = I \qquad (29)$$

by virtue of equation (21). As the left side is increasing in T given the maintained assumption $r+\delta>g$ and is increasing in x for all $I>0$, the implementation horizon increases with the cost and decreases with the match specific component of productivity, i.e. $\partial T/\partial I>0$ and $\partial T/\partial x<0$. The latter result is new and shows that technology in good matches is updated more frequently.

As implementation of new technology is optimal if and only if $T(x,I)$ is less than or equal to $T^0(x)$, implementation is optimal only for matches with specific productivity greater than the critical value R, which solves

$$T^0(R) = T(R,I). \qquad (30)$$

This result is also new and shows that if the match-specific productivity is poor, the firm will not update its technology but will keep the job open until profits drop to zero, at which point the job is destroyed and the worker made unemployed. But a good match is a scarce resource and the firm tries to preserve it by updating its technology on the job. The firm updates more frequently in better matches to take even more advantage of the higher job specific productivity. Not surprisingly, because $T(x,I)$ is increasing in I, $\partial R/\partial I>0$. In other words, the set of matches for which implementation is optimal falls with the cost.

To complete the description of an equilibrium, we simply note that the expected value of a job is the relevant incentive for job creation in this case. In other words, market tightness solves the following generalization of equation (11):

$$\frac{c\theta}{m(\theta,1)} + K = [1-F(b)]J \equiv \int_b^R J^0(x)dF(x) + \int_R^\infty J(x)dF(x). \tag{31}$$

As $J^0(x)$ is independent of I, $J(x)$ decreases with I, and equation (30) is equivalent to $J^0(R)=J(R)$, it follows that equilibrium market tightness decreases with the cost of implementation, i.e. $\partial\theta/\partial I\leq 0$.

Now, the flow of new jobs of match productivity x is $m(\theta,1)dF(x)$ and the fraction of these that survive to the age of obsolescence is $\exp\{-\delta T^0(x)\}$. Hence, the steady state equality of job creation and job destruction requires

$$JC = m(\theta,1)u[1-F(b)] = \delta n + m(\theta,1)u\int_b^{R(I)} e^{-\delta T^0(x)}dF(x) = JD. \tag{32}$$

Since $n=1-u$,

$$u = \frac{\delta}{\delta + [1-F(b) - \int_b^{R(I)} e^{-\delta T^0(x)}dF(x)]m(\theta,1)}. \tag{33}$$

Hence, the unemployment rate increases with implementation costs because the critical match productivity at which implementation is optimal increases, and because market tightness decreases with cost.

To determine the effects of an increase in the rate of technological progress on unemployment, we first note that equations (28) and (29) imply

$$\frac{\partial T^{0}(R)}{\partial g} < \frac{\partial T(R,I))}{\partial g} < 0. \qquad (34)$$

As a consequence, the critical implementation cut off increases with the rate of technical progress, i.e. $\partial R/\partial g > 0$. Hence, the job destruction rate generally increases with the growth rate both because the set of jobs for which implementation is optimal decreases and because the job destruction horizon decreases as g increases.

Because the effect of growth on the value of a job for which implementation is optimal is generally ambiguous, the effect of more rapid growth on job creation is also ambiguous. However, it is a simple matter to establish that the Proposition that we have proved for a given x applies for all x. In other words, a unique $I^*(x)$ exists such that $J(x)$ is increasing (decreasing) in g for all $I<(>)I^*(x)$. Consequently, the mean value theorem implies that an $I^* \in (\inf_x I^*(I^*(x))$ exists such that J, as defined in equation (31), is increasing (decreasing) in g for all $I<(>)I^*$. It follows that if the implementation cost is below the critical value I^*, both the job destruction rate and market tightness (and hence job creation) increase with the growth rate, implying larger gross job reallocation at higher rate of growth but with ambiguous effects on unemployment.

5. Factor Mobility

One of the neglected questions in the analysis of technological change and unemployment concerns the implications of factor mobility when sectors differ in their ability to adopt new technology. In our second extension of the basic model of sections 2 and 3 we study the implications of factor mobility for job creation, job destruction and unemployment when the economy consists of two sectors, one of which can implement the new technology at zero cost and the other cannot implement at any cost.

Perfect capital mobility implies that the expected returns from opening a job must be the same in each sector. We deal with this problem by requiring that the returns from a new vacancy be zero in each sector. Labor mobility implies that the expected returns from unemployed search in each sector be the same. This condition is automatically satisfied in our model by the assumption that there is a unified search market, so unemployed workers are not distinguished by sector in the matching process.

We consider the model without job-specific heterogeneity. As before, the overall matching rate in the economy is given by $m(v,u)$, where v and u represent aggregate vacancies and unemployment respectively. Denoting vacancies in the sector that adopts technology through job destruction by v_d and vacancies in the other sector by v_i, job creation in each sector is $m(v,u)v_d/v$ and $m(v,u)v_i/v$ respectively. The flow of workers to each job in each sector is therefore the common ratio $m(v,u)/v = m(?,1)/?$. The rate at which unemployed workers find jobs is as before, $m(?,1)$.

In order to ensure the existence of non-trivial solutions we assume the existence of diminishing returns to labor in each sector. Let $f(n)$, $f\mathbb{N}(n)<0$, represent output per worker in either sector, where n is sector employment, denoted by n_d and n_i respectively. We also assume that employers extract all rents from the job match, i.e. we work out the solutions for ß=0. Results with this assumption are easier to derive and, in the context of the simple formulation of this section, there is no loss of generality. As we have already shown, faster growth in a sector with zero implementation costs increases expected returns from job creation and decreases them in a sector with high costs, for all feasible ß.

The expected returns from opening a vacancy in each sector are given by equation (2). Since the rate at which workers arrive to jobs in each sector is the same, and if in addition we assume that both vacancy and job creation costs are common, the expected profit from new jobs, $J(t,0)$ must also be common across the two sectors.

Let now $J_d(t,0)$ be the expected returns from a new job in the creative destruction sector and $J_i(t,0)$ be the expected returns from a new job in the implementation sector. Substitution of I=0 and ß=0 into (17) and integration gives the expected returns in the implementation sector as $p(t)(f(n_i) - b)/(r+d-g)$. The expected returns in the destruction sector are given by (14). Introducing the $f(n_d)$ in place of x and the restriction ß=0 into this equation, we get

$$J^d = f(n_d)\left[\frac{1-e^{-(r+d)T^0}}{r+d} - e^{-gT^0}\frac{1-e^{-(r+\beta-g)T^0}}{r+d-g}\right] \tag{35}$$

and

$$f(n_d) = b\,e^{gT^0}. \tag{36}$$

Capital mobility then implies,

$$\frac{f(n_d)}{r+d}(1 - e^{-(r+d)T^0}) - \frac{b}{r+d-g}(1 - e^{-(r+d-g)T^0}) = \frac{f(n_i) - b}{r+d-g}, \tag{37}$$

Equilib

rium is defined by a solution for n_d, n_i, v_d, v_i, u, and T^0. The equations are (36), (37), the labor force condition,

$$n_i + n_d + u = 1, \tag{38}$$

the Beveridge curve equation[6]

$$\delta(n_i + n_d) + \frac{\delta e^{-\delta T^0}}{1 - e^{-\delta T^0}} n_d = m(v,u), \tag{39}$$

and the job creation condition,

$$\frac{f(n_i) - b}{r + \delta - g} = \frac{c}{m(v,u)/v} + K. \tag{40}$$

These are solved for the five unknowns, T^0, n_d, n_i, u, v. The distribution of vacancies in each sector can be obtained from the steady-state condition for employment in one of the two sectors, e.g.,

$$\delta n_i = v_i m(v,u)/v \tag{41}$$

Now for given employment levels, an increase in the growth rate decreases the left side of (37) because of the creative destruction effect and increases its right side because of the capitalization effect. Therefore, faster growth implies a reallocation of employment from the destruction sector to the implementation sector: the destruction sector creates fewer jobs, it destroys more and the implementation sector creates more jobs. It is clear from (39), however, that we cannot say what happens to equilibrium unemployment. The reallocation of employment does not influence the first term in (39) but the second term, which shows destruction through obsolescence, may go either up or down in the steady state, because both the destruction horizon and employment decrease in the sector. For sufficiently small values of the destruction horizon the effect of faster growth on unemployment is unambiguously negative, because the effect of the employment change in the destruction sector will dominate and steady-state job destruction through obsolescence will go down. But at higher T^0 we might have a situation where at faster growth there is more job creation in the implementation sector, more job destruction in the second sector, a reallocation of resources in favor of the implementation sector but with ambiguous effects on overall employment.

6. Conclusions

The relation between the arrival of new technology and the equilibrium number of jobs is quite complex. When new technology is embodied in new capital and investment is irreversible, faster rate of technological progress leads to more job destruction as firms get rid of their old capital and replace it with new and more productive kinds. But if the cost of implementing the new technology on the job is not high, firms will avoid destroying jobs and adopt the new techniques through implementation.

The effects of faster technological progress on job creation are more varied. With high implementation costs, job creation drops regardless of whether the firm decides to destroy obsolescent jobs or replace them with more productive ones without job destruction. In this case, faster rate of technological progress unambiguously gives rise to a lower equilibrium number of jobs. But if implementation costs are low, job creation is stimulated by faster productivity growth, leading to more jobs in equilibrium.

Of course, the reason for studying the role of implementation costs is that in an industrial economy implementation costs are likely to vary across firms, sectors or industries. In two extensions of our model we considered situations where firms that adopt the new technology through creative destruction and firms that adopt it through implementation co-exist. We have shown that faster technological progress leads to more gross job reallocation either across firms or across sectors, without necessarily implying lower equilibrium number of jobs. Clearly, once the model is extended in plausible directions, the solutions become too complex to handle analytically. We derived some analytical results here that point the way to empirical investigation but we postponed numerical and data analysis to later work. The lesson that has been learned is that we are not likely to find clear-cut associations between productivity growth and unemployment in aggregate data.

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ENDNOTES

1. The model is a generalization of our earlier model, which appeared in Mortensen and Pissarides (1994). The earlier model did not have technological progress.

2. Caballero and Hammour (1994) also examined the case of embodied technological progress but concentrated mainly on the analysis of the cyclical properties of job creation and job destruction, a question that we considered in Mortensen and Pissarides (1994).

3. Thus our model can also be interpreted as one where firms have different (more precisely, two) implementation costs and co-existence of creative destruction and on-the-job implementation.

4. See Bertola and Caballero (1994) for an analysis of job creation and job destruction when firms employ many workers.

5. The job creation side of the model is similar to that studied in Pissarides (1990, chapter 1).

6. The Beveridge curve equation is derived as before by equating job creation with job destruction in the economy. In the implementation sector, job destruction is given by dn_i. In the destruction sector by the remainder in the left side of (39), following an argument similar to the one underlying (15).