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TECHNOLOGY, UNEMPLOYMENT AND EFFICIENCY

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ABSTRACT

This paper analyzes technology choices and unemployment in search equilibrium. In contrast to standard search models, the presence of technology choices makes the decentralized equilibrium inefficient; there is too little investment in skills, too little job creation and there can be multiple equilibria. The paper also shows that technological progress is likely to be slower in labor markets where job tenure is low.

1 Introduction

Throughout recent history, technological progress has been the main factor ensuring a steady increase in wages and employment, and perhaps it is no coincidence that the past twenty years, which have witnessed below average productivity growth, have also been the period of unusually high unemployment. However, the link between technical change and the labor market is

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not unidimensional. Many firms cite labor market conditions and lack of adequate skills as a major deterrent to their adoption of new technologies, especially when these technologies are complementary to skills (see Northcott and Vickrey, 1993, Haskel and Martin, 1993).

Recent papers by Aghion and Howitt (1995), Mortensen and Pissarides (1995) and Saint-Paul (1991, 1994) discuss the relation between technological progress and unemployment. However, these papers do not include the skills of the workforce as a variable interacting with technology choices. How skills influence the direction of technological change is discussed in another recent literature, for instance Acemoglu, (1994, 1996a,b), but these papers do not contain a careful analysis of unemployment determination. The current paper proposes a simple extension of the standard search model of Diamond-Mortensen-Pissarides which enables a synthesis of the links between skills and technological change on the one hand and unemployment and technology on the other. The standard search model has been a very useful framework to analyze unemployment and labor market policy (see Pissarides, 1990), and one of its main implications is that as long as attention is limited to constant returns to scale matching technologies, the efficient allocation can be decentralized without any policy intervention (see Hosios, 1990). I show that this conclusion does not apply to an economy with endogenous technology choice, and neither the unemployment level nor the choice of technology is in general efficient. In particular, there can be a multiplicity of equilibria, and in one of the equilibria firms do not invest in skills because they expect their future workers to be unskilled.[1]

In addition to normative conclusions, the framework I introduce implies that high turnover is likely to discourage the adoption of new technologies. This is an interesting finding since both in the U.K. and the U.S. there has been an increase in low tenure jobs in the past two decades and the implications of this trend for technological choice have not yet been discussed.

[1] Multiplicity of equilibria can also arise in Acemoglu (1994,1996a), and Redding (1996) has recently extended these models to show the possibility of "low-skill" trap when there are technology ladders. Instead in this paper I use the framework developed in Acemoglu (1995a) which enables the simultaneous analysis of technology and employment. Pissarides (1992), Acemoglu (1994) and Robinson (1996) also investigate a related multiplicity of equilibria whereby firms do not create enough jobs when workers are unskilled, and when unemployment is high workers do not invest in skills, making different unemployment levels consistent with equilibrium.

2 The Model

The Environment

There is a continuum of workers normalized to 1 and a larger continuum of firms. All agents are infinitely lived, and maximize the present discounted value of their income stream with discount rate r. Each firm can decide to be inactive at zero return or can open a vacancy at flow cost γ. Each vacancy can only employ one worker.

Two technologies can be used for production. The first is the existing technology with cost normalized to 0. The second technology requires a new machine which costs δ and never depreciates. However, for the new machine to be used the worker who will operate it needs to acquire new skills, and the acquisition of these skills costs c. Both the adoption of the new machine and the investment in skills can be made at any point in time. Note also that the skills are not 'firm-specific', a worker can use these skills with any firm that has the same machine. Further the machine is *not* 'firm-specific' either and can be sold to other firms. I denote the flow rate of productivity of a skilled worker with the new machine by $y + \alpha$, and without either the skills or the machine, productivity is equal to y.

Employment relations are formed through a matching technology $M(u, v)$ where u is the number of unemployed workers, v is the number of vacancies and $M(u, v)$ is the flow rate of matches formed. As in the standard search analysis, I assume that $M(.,.)$ exhibits constant returns to scale in its two arguments, is continuous and differentiable, and that $M.,.) < \infty$. I define $\theta = \frac{v}{u}$ as a measure of the tightness of the labor market (see Pissarides, 1990). Then, the flow rate of match for an unfilled vacancy will be equal to $q(\theta)$ where $q'(.) < 0$ and the flow rate of a match for an unemployed worker is $Q(\theta) \equiv \theta q(\theta)$ with $Q'(.) > 0$. In contrast to the standard search models, in this economy there is potential heterogeneity because workers are either skilled or unskilled, and firms may or may not possess the new technology. I assume, as is standard in this type of models, that the matching technology is random in the sense that if the proportion of skilled workers in the unemployment pool is p, then the probability that a worker matching with a vacancy is skilled is also p.

Once formed, employment relations come to an end at the exogenous flow rate s. After termination, the worker looks for a new match while the job enters the state of an unfilled vacancy. The important assumption I am making here is that the probability of separation is independent from the productivity of the relation.

Analysis

The equilibrium will be characterized through a series of Bellman equations. I denote the (net present discounted) value of a firm with the new technology by J^N when the job is filled, and V^N when in the state of unfilled vacancy. Similarly, for a firm without the new technology I use J^O and V^O.

I start the analysis under the assumption that the new technology becomes available at time $t = 0$ when the system is in steady state. Each firm or vacancy can decide to adopt the new technology at any time $t \geq 0$ and an unskilled worker can be trained at any time. Since at $t = 0$ we are in steady state, the equilibrium unemployment level is $u = \frac{s}{s+\theta_0 q(\theta_0)}$ where θ_0 is the tightness of the labor market at $t = 0$. Next:

$$\begin{aligned} rJ^N - \dot{J}^N &= y + \alpha - w^N + s(V^N - J^N) \\ rV^N - \dot{V}^N &= q(\theta)\left((1-p)\max\left\{J^N - V^N - c + \sigma, J^{ON} - V^N, 0\right\} + p\left(J^N - V^N\right)\right). \end{aligned} \tag{1}$$

Let me briefly explain these equations. The first is a standard Bellman equation, it states that the per period value of being a filled vacancy with the technology is equal to the instantaneous capital gain $\dot{J}^N$, plus the per period dividend $y + \alpha - w^N$, plus the expected value of the capital loss as the asset may be lost and replaced by the value of unfilled vacancy. The second equation is more involved. A vacancy is matched with probability $q(\theta)$. The probability that the worker possesses the skills is p and in this case the firm will definitely accept the worker (as long as $y + \alpha \geq w^N$ which is assumed to be the case; recall p is the proportion of skilled workers in the unemployment pool). With probability $1 - p$, the worker is unskilled. The firm has then three viable options and it will choose whichever has higher present discounted value. The first is to accept the worker and train him, in which case it gets the value of a filled vacancy with a skilled worker, J^N; however, it will also incur the training cost c.[2] The second alternative is to employ

[2] It is assumed that the worker does not pay for the cost of training, which would be the case if workers are credit-constrained and binding contracts cannot be written. Acemoglu (1995a) analyzes a similar setting allowing

the worker without the necessary skills to utilize the new technology, in this case the firm will get the value of a filled vacancy with the new machine but without a skilled worker, J^{ON}. Finally, the firm may decide to turn down the worker and continue as an unfilled vacancy.

Value equations for firms without the new technology can be written as:

$$\begin{aligned} rJ^O - \dot{J}^O &= y - w^O + s(V^O - J^O) \\ rV^O - \dot{V}^O &= q(\theta)\left((1-p)\max\left(J^O - V^O\right) + p\max\left\{J^{NO} - V^N, 0\right\}\right). \end{aligned} \tag{2}$$

The only difference between these equations and (1) is that if the firm decides to employ a trained worker, it gets the value J^{NO} (note that I have not written the recursions for J^{ON} and J^{NO} in order to save space). Next, I assume that wages are set by static bargaining such that the wage of a worker is equal to a proportion β of his current output (other wage bargaining rules would not change the results).

To characterize the equilibrium, the evolution of p (the proportion of skilled workers in the unemployment pool) needs to be determined. For this I define ϕ as the proportion of active vacancies which adopt the technology, m as the proportion of skilled workers who are employed by firms without the new technology and n as the proportion of unskilled workers who are employed by firms with the new technology. Then;

$$\dot{p} = \frac{s(1-u)\left[\phi(1-n) + (1-\phi)m\right] - p\theta q(\theta)u}{u} = \theta q(\theta)\left[\phi(1-n) + (1-\phi)m - p\right] \tag{3}$$

In words, the change in the proportion of skilled workers in the unemployment pool is determined by entry and exit of skilled workers into the unemployment pool. Entry into the unemployment pool comes from employed workers $(1-u)$ at the rate s and a proportion ϕ of these workers are employed at firms with the new technology and a proportion $1-n$ of these are skilled. Similarly, a proportion $1-\phi$ are employed at firms without the new technology and a proportion m of these workers are skilled. Finally, m and n are determined from the Bellman equations given above by seeing whether firms are willing to hire different types of workers.

Since there is an infinite supply of firms able to open a vacancy, $V^O > 0$ is not consistent with equilibrium and since a firm will never open a loss making vacancy, $V^O < 0$ is also not possible,

workers to pay for their training, and the qualitative results are not changed.

thus $V^O = 0$. Similarly, $V^N > \delta$ can be ruled out, but to rule out $V^N < \delta$ we need new firms willing to invest in the machine so that the firm can sell its machine to one of these firms at the price $\delta - \epsilon$ for ϵ arbitrarily small. Thus, when there are new firms willing to invest $V^N = \delta$.

Given these no-arbitrage conditions, (1) and (2) immediately imply:

$$
\begin{aligned}
J^N(t) &= \frac{(1-\beta)(y+\alpha)+s\delta}{r+s}, \\
J^O(t) &= \frac{(1-\beta)y}{r+s},
\end{aligned}
\tag{4}
$$

where I have explicitly introduced time-dependence to emphasize that in equilibrium (due to free-entry) J^N and J^O are independent of time. However, clearly p is potentially time-dependent and this is ensured via θ, the tightness of the labor market depending on time in order to satisfy $V^N - \delta = V^O = 0$ in (1) and (2).

When is a new technology adopted? By adopting the firm gets J^N but loses J^O, incurs the cost $\delta + c$. Thus, the technology will be adopted by all firms employing a worker if and only if:

$$
\begin{aligned}
J^N &\geq J^O + \delta + c, \text{ that is:} \\
\alpha &\geq \alpha_1(\theta_0) \equiv \frac{r\delta + (r+s)c}{1-\beta}.
\end{aligned}
$$

Note that if $\alpha < \alpha_1(\theta_0)$, at time $t = 0$ the innovation is not adopted, then the profitability of vacancy creation is unchanged and θ remains constant at θ_0, and therefore, the new technology never gets adopted. In contrast if $\alpha > \alpha_1(\theta_0)$, then all active firms buy the new machine at $t = 0$, and we have $\phi = 1$ and $n = 1$. This implies from (3) that p will increase over time until it reaches 1, i.e. until all workers are trained. As p increases, (1) implies that expected returns of unfilled vacancies will also increase, and to satisfy the zero-profit condition θ needs to increase until it reaches some higher value θ_1. Since the job-finding rate, $\theta q(\theta)$,is increasing in θ, the equilibrium rate of unemployment will also fall after the new technology is adopted. Therefore:

Result 1 : If $\alpha \geq \alpha_1(\theta_0)$, there exists an equilibrium in which the new technology is adopted. In this equilibrium, firms train all unskilled workers immediately and the proportion of trained workers, p, asymptotically tends to 1, the tightness of the labor market increases from θ_0 to θ_1 and unemployment falls.

The analysis up to this point was conducted under the assumption that there are always new firms that enter and want to buy the existing machines which keeps $V^N = \delta$. Suppose instead that we are in a situation where $\alpha \geq \alpha_1$ but no firm contemplates adopting the new technology. Is it still profitable for a firm to do it alone? In other words, can a coordination failure arise?

A coordination failure

Suppose the firm expects that no other firm will adopt the new technology. Then, $V^N \neq \delta$ because there are no new firms to buy the machine. Since the firm cannot sell the machine when the worker separates, it will have to keep it until it finds a worker, therefore (1) needs to be solved under the assumption that $p = 0$ (this is because no other firm innovates so all workers are unskilled) together with $\gamma = q(1-\beta)y$ (from (1)) and without $V^N = \delta$. Simple algebra yields:

$$J^N = \frac{(r+q(\theta))\,(1-\beta)(y+\alpha) - s\gamma - sq(\theta)c}{r(r+q(\theta)+s)} \tag{5}$$

We obtain that the new technology will be adopted if and only if:

$$\alpha \geq \alpha_0(\theta_0) \equiv r\frac{(r+s+q(\theta))}{(r+q(\theta))\,(1-\beta)}\delta + \frac{(r+s)c}{1-\beta} \tag{6}$$

It is easy to see that $\alpha_0(\theta_0) > \alpha_1(\theta_0)$, since the coefficient in front of δ is larger in $\alpha_0(\theta_0)$. Expressed differently, when firms believe others will not adopt the new technology, *the effective cost* of adoption increases. Thus:

Result 2 : If $\alpha \in (\alpha_1(\theta_0), \alpha_0(\theta_0))$, there exist two pure strategy symmetric equilibria. In one the innovation is adopted and in the other it is not. In the first equilibrium, unemployment is lower.

When all firms adopt the innovation, the future workforce is skilled because firms train their workers. As a result, even if the current employment relation comes to an end, a new productive relation with a skilled worker will be able to make high profits, and therefore, there will be some firm willing to buy the new machine, and this why the value of an unfilled vacancy with the new machine, V^N, never falls below δ. However, when no other firm innovates, the future workforce is untrained, and a firm which adopts the new technology will have to pay for the training of the unskilled workers it will recruit in the future. The anticipation of these costs reduces the profitability of the investment. Because of these considerations, no other firm wants to buy the machine from the current owner, and therefore V^N falls below δ. As a result, adopting the new technology is less profitable. The intuition for this multiplicity is an extension of the result in Acemoglu (1995a) where when the future workforce is untrained, the profitability of new technologies is reduced. However, instead of a two period model of Acemoglu (1995a), the result of this paper is derived in an infinite horizon model, and the matching aspect is explicitly modelled, firms are allowed to choose the timing of their innovation and training, and to sell the machine when they have no use for it, and there is a free-entry condition to determine the number of firms and vacancies.

The efficient allocation

Is one of these equilibria efficient? To answer this question, I write down the additional social surplus from adopting the technology and training the worker by S^N and the additional social value of a trained worker is denoted by Υ^T.[3] Then, we have:

$$\begin{aligned} rS^N - \dot{S}^N &= y + \alpha + s(\delta + \Upsilon^T - S^N) \qquad (7) \\ r\Upsilon^T &= \theta q(\theta)\left(c - \Upsilon^T\right) \end{aligned}$$

Intuitively, the social planner is also affected by the search frictions, but like the decentralized market, she can transfer the machine from a destroyed job to a new one; this explains δ in the equation for S^N. The equation for Υ^T can be explained by noting that a trained worker saves the society c when he matches with a firm because the training costs can be avoided.

The social planner will adopt the new technology if and only if $S^N \geq \delta + c$ which implies:

$$\alpha \geq \alpha_S \equiv r\delta + (r+s)c - \frac{s\theta q(\theta)c}{r + \theta q(\theta)}. \qquad (8)$$

Result 3 : $\alpha_S(\theta) < \alpha_1(\theta) < \alpha_0(\theta)$.

This result states that both of the decentralized equilibria characterized above have too weak

[3] And I hold the tightness of the market at some θ_s. It is straightforward to see that if she adopts the technology, the social planner would like to increase θ, thus she would generate even more surplus from adopting the new technology, thus $\alpha_S(\theta)$ I derive is an upper bound on the cut-off level of the productivity of the new innovation. Therefore, the difference between the decentralized economy and the constrained optimal allocation is even larger.

incentives to adopt the new technology. The intuition is partly given by the above discussion. Firms are discounting the future at the rate $r+s$ because their employment relation comes to an end at the rate s, and after this point they receive no benefit from the worker's additional skills. Instead, his future employer gets the higher return (see also Acemoglu, 1995b for a discussion of a similar result). Also firms are discouraged from investing because for all $\beta > 0$, part of the additional returns will be captured by the worker. However, the qualitative results are not affected when $\beta = 0$ as it can be seen by comparing $\alpha_1(\theta)$ and $\alpha_0(\theta)$ to $\alpha_S(\theta)$ for $\beta = 0$, therefore, the distortions caused to rent-sharing are not the only source of inefficiency (see Acemoglu, 1995a, for discussion).

Moreover, as the decentralized economy invests too little in the new technology compared to the efficient allocation, its unemployment rate is too high because there is not enough job creation. This result contrasts with the standard search models where the amount of job creation and unemployment is efficient as long as β is chosen correctly to regulate the entry of firms. I show here that no value of β restores efficiency, thus the decentralized equilibrium does not do a good job of internalizing the externalities that arise because of the productivity differences of workers (see also Acemoglu, 1996a).

A simple comparative static

The framework I have proposed is not only useful in showing the potential inefficiencies, but it also provides an interesting prediction related to the links between turnover and new technologies.

Result 4 : The higher is s, the weaker are the incentives to adopt new technologies and also the more distorted are the innovation decisions.

Intuitively, as noted above, firms discount the future at the rate $r+s$, thus when s increases, they are less willing to invest. Moreover, because the social planner discounts the future at a lower rate, an increase in s also makes the inefficiencies more severe. A high level of s corresponds to a market with high turnover and low tenure. Thus, labor markets with low tenure are not conducive to the adoption of new technologies. It is also worth noting that since all human and physical capital are general, in the absence of matching and credit market imperfections, there would be no link between s and innovation in this economy (i.e. in the competitive analogue of this economy, the innovation would be adopted if and only if $\alpha \geq r(\delta + c)$).

This result is interesting in two respects: first, many commentators and scholars suggest that the life-time employment relation in Japanese corporations is an important factor contributing to fast technological change in Japan (e.g. Hashimoto, 1991). Second, the typical tenure of a worker appears to have decreased recently in the U.S. and U.K. (see for instance Farber, 1996) and this result suggests that this recent trend may have unforeseen consequences on the rate of technological progress.

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