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**Productivity Growth and Employment:  
Theory and Panel Estimates**

**Christopher A. Pissarides and Giovanna Vallanti**

## **Abstract**

Theoretical predictions of the effect of TFP growth on employment are ambiguous, and depend on the extent to which new technology is embodied in new jobs. We estimate a model for employment, wages and investment with an annual panel for the United States, Japan and Europe and find that TFP growth increases employment. For the United States TFP growth explains the trend change in unemployment. We evaluate the model and find that creative destruction plays no part in aggregate unemployment dynamics. The model can explain up to half of the estimated impact of growth on unemployment.

Keywords: TFP growth, employment, creative destruction, capitalization effect, unemployment dynamics, embodied technology

JEL Classification: E24, J64, O51, O52

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# 1 Introduction

The purpose of this paper is to evaluate the relation between growth in total factor productivity (TFP) and aggregate employment. Authors who looked at this relation in the theoretical literature concluded that the impact of TFP growth on employment is ambiguous.<sup>1</sup> We bring together results in a simplified equilibrium model, with employment, wages and the capital stock as unknowns, which shows that the net impact of TFP growth on employment is negative when new technology is embodied in new jobs but positive when it is disembodied.<sup>2</sup> We then estimate the impact of TFP growth on employment, wages and the capital stock with annual panel data for the United States, Japan and twelve of the countries of the European Union. The estimates show that TFP growth has a strong positive impact on all three unknowns. It can explain virtually all changes in trend unemployment in the United States in 1965-1995. It can also explain a large fraction of the changes in European unemployment.<sup>3</sup>

The final task of the paper is to use the estimates to evaluate the models used to study the relation between TFP growth and employment, and make inferences about the degree to which new technology is embodied in new jobs.

Our empirical results are inconsistent with the Schumpeterian assumption of embodied technology and creative destruction. We find support for the Solow assumption of disembodied technology. We also find evidence that the channels identified in perfect-foresight search-equilibrium models with a Nash solution for wages are not strong enough to explain the full estimated impact of TFP growth on employment. We show that a more naive wage equation than the one that we use can increase the impact of TFP growth on employment in the quantitative model, mirroring results obtained by Shimer (2003) and Hall (2003) for cyclical unemployment.

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<sup>1</sup>See, for example, Aghion and Howitt (1994) and Mortensen and Pissarides (1998), who model long-term effects of growth on employment. Other authors, e.g. Phelps (1994) and Ball and Moffit (2002) argue that the effects of growth on employment are unambiguous but temporary.

<sup>2</sup>It should be emphasized that when we say embodied technology, we mean embodied in new jobs, not only in new capital. Technology may be embodied in new capital, like a later version of Microsoft Windows that may need a more powerful computer, but not embodied in new jobs, because the worker who worked with the previous version of MS Windows keeps her job and learns how to use the new version. In this paper we have nothing to say about technology that is embodied or disembodied in new capital.

<sup>3</sup>See Staiger et al. (2002) for the trend dynamics of US unemployment. We show that our predicted unemployment series when only TFP is allowed to vary tracks well their constructed univariate unemployment trend (the “NAIRU”).

Our model is new but draws heavily on models with frictions and quasi-rents by Pissarides (2000, chapter 3), Aghion and Howitt (1994), Mortensen and Pissarides (1998) and others. Its focus is the demand side of the labor market, the job creation and job destruction decisions of firms.<sup>4</sup> Its steady state is characterized by balanced growth with unknowns the rate of employment, the rate of unemployment, the capital stock and the wage rate, and exogenous variables TFP growth, the cost of capital and the labor force (and some other institutional variables). Our key assumption is that if there is aggregate TFP growth at some rate  $a > 0$ , productivity in existing jobs grows on average at a lower rate  $\lambda a$ , with  $\lambda \in [0, 1]$ , because some new technology is embodied in new jobs and existing jobs cannot benefit from it. Faster TFP growth decreases overall employment for low  $\lambda$  but increases it for high  $\lambda$ . One objective of our empirical work is to obtain a plausible value for  $\lambda$ .

In our empirical model we find that although on impact faster TFP growth temporarily decreases employment, most likely because job destruction reacts faster to shocks than job creation does, after the first year the response turns positive and continues increasing for a few more years. This requires a high value for  $\lambda$ . We show that our estimates imply that  $\lambda$  is close to unity (in the range 0.96 to 1), implying that on average the fraction of new technology that cannot be adopted by existing jobs is too small to matter in aggregate steady-state dynamics. Of course, this does not preclude substantial incidence of “creative destruction” in individual sectors undergoing fast technological change, or individual firms restructuring after the discovery of new technology. Our aggregate findings, however, are consistent with other recent empirical work, which also finds strong positive correlations between aggregate productivity growth and employment.<sup>5</sup>

The introduction of frictions and quasi-rents into models of growth complicates the analytics and the models are usually solved only for their steady states. There has been virtually no work on the out-of-steady-state properties of growth models with frictions.<sup>6</sup> This poses a problem for econometric work, since the data that we use to estimate the model are generated in real economies, whose adjustment to the steady state in response to TFP shocks may take several years.

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<sup>4</sup>See the notes to the literature in Pissarides (2000, chapter 3) for a brief discussion of more references. There is a related literature that derives the effects of productivity growth from the supply side, see e.g., Phelps (1994) and Ball and Moffitt (2002) and the discussion in section 7 below.

<sup>5</sup>See for example Phelps (1994), Fitoussi et al. (2000), Ball and Moffitt (2002) and the introductory remarks by Krueger and Solow (2002, p. xxiii).

<sup>6</sup>A notable exception is the recent paper by Postel-Vinay (2002), which calibrates the out-of-steady-state behavior of the Schumpeterian model discussed below.

Our approach is to write and solve the steady-state version of the model and derive some empirical restrictions on the steady-state behavior of our endogenous variables. We then impose and test these restrictions on the steady-state solution of the estimated empirical model. But in the estimation we allow for data-driven unrestricted lags in the adjustment to the steady state. We simulate the estimated adjustment paths and show that although steady states are stable and satisfy our restrictions, the simulated adjustment paths can be very long.

The paper is organized as follows. Section 2 describes and solves the theoretical model. Section 3 takes the model's structural equations and explains the derivation of the three estimated equations. Section 4 describes our data and the growth accounting that we used to calculate TFP growth for each country in our sample, and briefly discusses some econometric issues. Section 5 presents the results of the econometric analysis and uses the results to simulate the effects of the observed productivity changes. Section 6 calculates the fraction of TFP growth embodied in new jobs and evaluates the theoretical model.

## 2 The Model

We model employment by deriving steady-state rules for job creation and job destruction for the representative firm. The key to the derivation of growth effects is to assume that job creation requires some investment on the part of the firm, which may be a set-up cost or a hiring cost. Both firm and worker will want such jobs to last and so they care about the way that the marginal product and wage rate evolve over time.

In the steady state growth influences job creation through capitalization effects and job destruction through obsolescence. The precise influence on each, however, depends on whether new technology can be introduced into ongoing jobs, or whether it needs to be embodied in new job creation. In order to write a model that can be matched to the data we assume that there are two types of technology. One, denoted by  $A_1$ , can be applied in existing jobs as well as new ones, as in the Solow model of disembodied technological progress. The other, denoted by  $A_2$ , can only be used by new jobs, an idea attributed to Schumpeter (see Aghion and Howitt, 1994). We let the rate of growth of  $A_1$  be  $\lambda a$  and the rate of growth of  $A_2$  be  $(1 - \lambda)a$ , with  $0 \leq \lambda \leq 1$ , so the total rate of growth of technology is  $a$ . Both  $\lambda$  and  $a$  are parameters. The parameter  $\lambda$  measures the extent to which technology is disembodied. If  $\lambda = 0$  we have the extreme Schumpeterian model of embodied technology but if  $\lambda = 1$  all technology is disembodied. The parameter  $a$  is the growth rate of

TFP in the steady state and is observable. The parameter  $\lambda$  is unobservable by the econometrician but an approximate value for it may be inferred from our empirical estimates.

Both technologies are labor augmenting and the production function is Cobb-Douglas. The firm creates new jobs on the technological frontier, adopting the most advanced technology of both types. But because existing jobs cannot benefit from embodied technological progress, jobs move off the frontier soon after creation. We denote output per worker by  $f(\cdot, \cdot)$ . The first argument of  $f(\cdot, \cdot)$  denotes the creation time of the job (its vintage) and the second the valuation (current) time. At time  $\tau$ , output per worker in new jobs is

$$f(\tau, \tau) = A_1(\tau)^{1-\alpha} A_2(\tau)^{1-\alpha} k(\tau, \tau)^\alpha, \quad (1)$$

where  $k(\tau, \tau)$  is the capital-labor ratio in new jobs at  $\tau$ . But in jobs of vintage  $\tau$  output per worker at time  $t > \tau$  is

$$f(\tau, t) = A_1(t)^{1-\alpha} A_2(\tau)^{1-\alpha} k(\tau, t)^\alpha, \quad (2)$$

where in general  $k(\tau, t) \neq k(t, t)$ . Note that in (2) the disembodied technology  $A_1$  is updated but the embodied technology  $A_2$  is not.

When the firm creates a job it keeps it either until an exogenous process destroys it, an event that takes place at rate  $s$ , or until it destroys the job itself because of obsolescence, which takes place  $T$  periods after creation.<sup>7</sup> There is a perfect market for capital and the firm re-sells its capital stock when the job is destroyed. Capital depreciates at rate  $\delta$  and in order to focus on employment we assume that there are no capital adjustment costs. When the job is destroyed the employee is dismissed at zero cost.

The value of the typical job consists of two parts, the value of its capital stock and a value  $V(\cdot, \cdot) \geq 0$ , which is due to the frictions and the quasi-rents that characterize employment. The value of a job created at time 0 and lasting until  $T$  satisfies the Bellman equation, for  $t \in [0, T]$ ,

$$\begin{aligned} r(V(0, t) + k(0, t)) &= f(0, t) - \delta k(0, t) - w(0, t) - sV(0, t) + \dot{V}(0, t) \\ V(0, T) &= 0. \end{aligned} \quad (3)$$

All variables have been defined except for  $r$ , the exogenous rental rate of capital, and  $w(0, t)$ , the wage rate at  $t$  in a job of vintage 0. The interpretation of this equation is the one that has become familiar from search theory. The

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<sup>7</sup>A second endogenous job destruction process could be introduced along the lines of Mortensen and Pissarides (1994), with the firm's productivity being subject to idiosyncratic shocks. This generalization would increase both the complexity and richness of the model, but it is an unnecessary complication for the estimation purposes in hand.

firm hires capital stock  $k(0, t)$  and makes net (super-normal) profit  $V(0, t)$ , which it loses when the job is destroyed. The capital stock  $k(0, T)$  is re-sold.

The firm's controls at time 0 are (a) whether or not to create a job worth  $V(0, 0)$ ; and if it creates it, (b) when to terminate it, and (c) the path of  $k(0, t)$  for  $t \in [0, T]$ . The wage rate is also a control variable but we assume that it is jointly determined by the firm and the worker after a bargain. We take each of these decisions in turn, starting with capital.

## 2.1 Capital accumulation

Maximization of (3) with respect to  $k(0, t)$  yields the condition

$$k(0, t) = A_1(t)A_2(0)(\alpha/(r + \delta))^{1/(1-\alpha)} \quad t \in [0, T]. \quad (4)$$

When  $t = 0$ , this expression refers to new jobs. The path of the capital-labor ratio in pre-existing and new jobs follows immediately:

$$k(0, t) = e^{\lambda at} k(0, 0) \quad (5)$$

$$k(t, t) = e^{at} k(0, 0). \quad (6)$$

New jobs are technologically more advanced than old jobs and also have more capital than old jobs.

With (4)-(6) it is possible to derive some useful expressions for output and labor's marginal product. From (1) and (2) we find that the evolution of output per worker in the typical job also satisfies expressions similar to (5) and (6). From (2) and (4) labor's marginal product is

$$\phi(\tau, t) \equiv f(\tau, t) - (r + \delta)k(\tau, t). \quad (7)$$

Clearly, given (5) and (6),

$$\phi(0, t) = e^{\lambda at} \phi(0, 0), \quad (8)$$

$$\phi(t, t) = e^{at} \phi(0, 0). \quad (9)$$

It follows from these expressions that when technology on the frontier grows at rate  $a$ , output, the capital stock and labor's marginal product in existing jobs grow at the lower rate  $\lambda a$ . They jump up to the technological frontier when the job is destroyed and a new one created in its place.

Because of (4), the solution to (9) is

$$\phi(t, t) = A_1(t)A_2(t)(1 - \alpha) \left( \frac{\alpha}{r + \delta} \right)^{\frac{\alpha}{1-\alpha}} \quad \forall t. \quad (10)$$

We introduce for future reference the notation

$$\phi \equiv (1 - \alpha) \left( \frac{\alpha}{r + \delta} \right)^{\frac{\alpha}{1-\alpha}}. \quad (11)$$

## 2.2 Wages

The wage equation plays a key role in the transmission of the effects of growth to employment. We showed that the marginal product of labor in existing jobs grows at the rate  $\lambda a$ . We now show that because of competition from new jobs, wages in existing jobs grow at faster rate, and so eventually jobs become unprofitable.

When a job is created at time 0 the firm enjoys net payoff  $V(0, 0)$ , obtained as the solution to (3). In order to determine wages we derive the worker's payoffs, as follows. In unemployment, in period  $t$  the worker enjoys payoff  $U(t)$ , given by

$$rU(t) = b(t) + m(\theta)(W(t, t) - U(t)) + \dot{U}(t), \quad (12)$$

where  $b(t)$  is unemployment income,  $\theta \geq 0$  is a measure of market tightness,  $m(\theta)$  is the rate at which new job offers arrive to unemployed workers and  $W(t, t)$  is the present discounted value of wage earnings in a new job accepted at time  $t$ . We assume  $m'(\theta) > 0$ ,  $m(0) = 0$  and  $m(\theta) \rightarrow \infty$  as  $\theta \rightarrow \infty$ . We also assume no search on the job and that  $b(t)$  grows at the rate  $a$ , the average rate of growth of productivity in the economy as a whole, an assumption that could be supported by making unemployment income proportional to mean wages. It is, however, easier and as general to write, at least for the moment,

$$b(t) = A_1(t)A_2(t)b, \quad (13)$$

where  $b \in [0, \phi)$  is a parameter. The restriction that  $b$  is strictly below  $\phi$  is required to ensure that market production is preferable to unemployment.

The present discounted value of earnings in a job of vintage  $\tau$  satisfies the Bellman equation, for  $t \in [\tau, \tau + T]$ ,

$$\begin{aligned} rW(\tau, t) &= w(\tau, t) + s(U(t) - W(\tau, t)) + \dot{W}(\tau, t) \\ W(\tau, \tau + T) &= U(\tau + T). \end{aligned} \quad (14)$$

Wages in each job share the quasi-rents that the job creates. The firm's rents are the solution to (3),  $V(\tau, t)$ , and the worker's rents are the difference  $W(\tau, t) - U(t)$ . We assume

$$W(\tau, t) - U(t) = \frac{\beta}{1 - \beta} V(\tau, t), \quad (15)$$

where  $\beta \in [0, 1)$  is the share of labor. This sharing rule is usually known in



the literature as the Nash sharing rule. Standard manipulations yield<sup>8</sup>

$$w(\tau, t) = (1 - \beta)b(t) + \beta m(\theta)V(t, t) + \beta\phi(\tau, t). \quad (16)$$

We introduce the notation

$$\omega(t) \equiv b(t) + \frac{\beta}{1 - \beta}m(\theta)V(t, t) \quad (17)$$

and refer to  $\omega$  as the reservation wage.<sup>9</sup> The important feature of  $\omega$  is that it captures the external influences on wages, resulting from the attractions of quitting to search for alternative employment.

Unemployment income  $b(t)$  grows at rate  $a$  by assumption and it follows immediately from (3), (17) and (16) that both  $V(t, t)$  and  $w(t, t)$  also grow at rate  $a$ . Therefore, we can write the wage equation as the weighted average of the reservation wage and marginal product, with labor's share acting as weight. The reservation wage is the "outside" component and grows at rate  $a$ , and marginal product is the "inside" component and grows at rate  $\lambda a$ . For a job created at time 0 the wage equation is

$$w(0, t) = (1 - \beta)\omega(0)e^{at} + \beta\phi(0, 0)e^{\lambda at}. \quad (18)$$

Given (9) it now follows that wages in new jobs grow at rate  $a$ :<sup>10</sup>

$$w(t, t) = e^{at}w(0, 0). \quad (19)$$

Equations (18) and (19) contrast with (5)-(6) and (8)-(9). In new jobs wages, the capital stock and technology grow at the same rate  $a$ . In existing jobs technology and the capital stock grow at the same rate  $\lambda a$  but wages grow at a faster rate, which lies between  $a$  and  $\lambda a$ .

### 2.3 Job creation and job destruction

The differential rates of growth of TFP, capital and wages in existing jobs drive the results on employment. We integrate (3) to arrive at the present

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<sup>8</sup>Make use of (15) to substitute  $W(t, t) - U(t)$  out of (12). Subtract the resulting equation from (14) and use the result to substitute  $W(\tau, t) - U(t)$  out of (15). Finally, use (3) to substitute  $V(\tau, t)$  out of (15) and collect terms, noting that (15) also holds in the time derivatives because of the assumption of continuous renegotiation.

<sup>9</sup>A worker accepts a job that pays a wage  $w$  if and only if  $w/(r - a) \geq U$ , where  $a$  is the rate of growth of wages in the steady state. Therefore the reservation wage is  $(r - a)U$ . From (12) and (15)  $rU = \omega + \dot{U}$ , which in a balanced growth equilibrium is  $rU = \omega + aU$ , giving the reservation wage as  $\omega = (r - a)U$ .

<sup>10</sup>See also below for more discussion of the mean wage equation.

discounted value of profit from a job of vintage 0:

$$V(0, 0) = \int_0^T e^{-(r+s)t} (\phi(0, t) - w(0, t)) dt. \quad (20)$$

Making use of (8) and (18), we re-write (20) as

$$V(0, 0) = (1 - \beta) \int_0^T e^{-(r+s)t} (e^{\lambda at} \phi(0, 0) - e^{at} \omega(0)) dt. \quad (21)$$

We simplify the notation by noting that because of (10), (17) and (13),  $V(0, 0)$ ,  $\phi(0, 0)$  and  $\omega(0)$  are all proportional to the level of aggregate technology,  $A_1(0)A_2(0)$ . Therefore we can omit the time notation and write (21) as

$$V = (1 - \beta) \int_0^T e^{-(r+s)t} (e^{\lambda at} \phi - e^{at} \omega) dt, \quad (22)$$

where  $\phi$  was defined in (11) and

$$\omega = b + \frac{\beta}{1 - \beta} m(\theta) V. \quad (23)$$

The firm chooses the obsolescence date  $T$  to maximize the job's value. Differentiation of (22) with respect to  $T$  gives:

$$T = \frac{\ln \phi - \ln \omega}{(1 - \lambda)a}, \quad (24)$$

at which date the reservation wage becomes equal to the worker's marginal product.

Figure 1 illustrates the firm's optimal obsolescence policy. The horizontal axis shows time and the vertical axis measures the log of the marginal product of labor and wages. The broken line shows the path of marginal product if the job were to stay on the technological frontier, which grows at rate  $a$ . The continuous parallel line below it shows the reservation wage, which also grows at rate  $a$ . A new job is created on the frontier at time 0 but the marginal product of labor in it grows at the lower rate  $\lambda a$ , shown by the flatter continuous line. Eventually, the marginal product hits the reservation wage line and the job is destroyed. The firm then (or another firm) creates another job in its place, with marginal product on the frontier.<sup>11</sup>

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<sup>11</sup>Note that the wage rate paid by the firm is a weighted sum of the reservation wage and the marginal product. So, because marginal product takes a jump at  $T$ , wages also take a (smaller) jump, but the reservation wage does not jump.

It follows from figure 1 and (24) that if all technology is of the Solow disembodied type,  $\lambda = 1$ , marginal product in figure 1 remains on the frontier and the firm will never want to destroy a job through obsolescence. Job destruction in this case takes place only because of the exogenous separation process, and for aggregate employment  $L$  aggregate job destruction is  $sL$ , independent of growth. But if  $\lambda < 1$  faster growth (which makes all lines in figure 1 steeper) leads to more job destruction, as by differentiation of (24),  $\partial T/\partial a < 0$ . But this effect is partial because the reservation wage also depends on the growth rate. If it is confirmed by the general equilibrium analysis, aggregate job destruction in this case has two components, one again given by  $sL$  and the other given by all the surviving jobs of age  $T$ , which become obsolete.

To derive the equilibrium effect of growth we integrate (22) to obtain:

$$V = (1 - \beta) \left( \frac{1 - e^{-(r+s-\lambda a)T}}{r + s - \lambda a} \phi - \frac{1 - e^{-(r+s-a)T}}{r + s - a} \omega \right). \quad (25)$$

For convenience, we introduce a new symbol for the coefficients inside the brackets:

$$y(\lambda a) \equiv \frac{1 - e^{-(r+s-\lambda a)T}}{r + s - \lambda a}, \quad \lambda \in [0, 1], \quad (26)$$

so the returns from a new job, (25), simplify to:

$$V = (1 - \beta)(y(\lambda a)\phi - y(a)\omega). \quad (27)$$

By differentiation,

$$y'(\lambda a) > 0, \quad y''(\lambda a) < 0. \quad (28)$$

In order to derive now the influence of the growth rate on job creation and close the model, suppose that jobs are created at some cost, and that the cost increases in the number of jobs created at any moment in time. A number of alternative assumptions can be used to justify this assumption and give the required result. We follow the search and matching literature, which assumes that at the level of the firm the cost of creating one more job is constant but marginal costs are increasing at the aggregate level because of congestion effects (see Pissarides, 2000). Let our measure of tightness,  $\theta$ , be the ratio of the aggregate measure of firms' search intensities (e.g., the total number of advertised vacant jobs), to the number of unemployed workers. Then given the rate of arrival of jobs to workers,  $m(\theta)$ , the rate of arrival of workers to jobs is  $m(\theta)/\theta$ . Consistency requires that this rate decrease in  $\theta$ , which is satisfied when the elasticity of  $m(\theta)$  is a number between zero and one. We denote this elasticity by  $\eta \in (0, 1)$  (which is not necessarily a constant).

We now assume that the cost of creating one more job in period  $t$  is a flow cost  $A_1(t)A_2(t)c$  for the duration of the firm's search for a suitable worker. The proportionality of the cost to technology is an innocuous simplification (but of course that the cost should be increasing at rate  $a$  is necessary for the existence of a steady state). Letting  $V^0(t)$  denote the present value of search for the firm (equivalently, the value of creating one more vacant job), the following Bellman equation is satisfied:

$$rV^0(t) = -A_1(t)A_2(t)c + \frac{m(\theta)}{\theta}(V(t, t) - V^0(t)) + \dot{V}^0(t). \quad (29)$$

Under free entry into search,  $V^0(t) = \dot{V}^0(t) = 0$ , and so each new job has to yield positive profit, which is used to pay for the expected recruitment costs. In period  $t = 0$  the job creation condition is:

$$V(0, 0) = A_1(0)A_2(0)\frac{c\theta}{m(\theta)}, \quad (30)$$

or equivalently,

$$V = \frac{c\theta}{m(\theta)}. \quad (31)$$

We are now in a position to describe the determination of the optimal destruction time  $T$  and the equilibrium market tightness  $\theta$ . Conditions (17), (13) and (31) are common to all firms and workers and can be used to yield the following equilibrium relation between  $\omega$  and  $\theta$ :

$$\omega = b + \frac{\beta}{1 - \beta}c\theta. \quad (32)$$

Substitution of  $V$  from (27) into (31) gives the following, which is another equilibrium relation between  $\omega$  and  $\theta$ :

$$(1 - \beta)(y(\lambda a)\phi - y(a)\omega) = \frac{c\theta}{m(\theta)}. \quad (33)$$

Because (33) satisfies the envelope theorem with respect to  $T$ , in the neighborhood of equilibrium (33) gives a downward-sloping relation between  $\omega$  and  $\theta$ .<sup>12</sup> But (32) gives a linear upward-sloping relationship, so (33) and (32) are uniquely solved for the pair  $\omega, \theta$  for any value of  $T$ . Given this solution for  $\omega$ , (24) gives the optimal  $T$ . Job creation at time  $t$  in this economy is given

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<sup>12</sup>Outside the neighborhood of steady-state equilibrium the relation between the job creation condition and  $\theta$  may not be monotonic. See Postel-Vinay (2002) for a demonstration in a related model.

by  $x(t) = \tilde{u}(t)m(\theta)$ , where  $\tilde{u}(t)$  is the predetermined number of unemployed workers and  $m(\theta)$  is the matching rate for each worker.

In order to obtain the effect of TFP growth on job creation, for given unemployment, we differentiate (33) with respect to  $a$  to obtain:

$$\left( \frac{c\beta y(a)}{1-\beta} + \frac{c(1-\eta)}{m(\theta)} \right) \frac{\partial \theta}{\partial a} = (1-\beta) (\lambda y'(\lambda a)\phi - y'(a)\omega) \quad (34)$$

where, as already defined,  $\eta \in (0, 1)$  is the elasticity of  $m(\theta)$ . The coefficient on  $\partial\theta/\partial a$  is positive but the right-hand side can be either positive or negative. By (28), at  $\lambda = 0$ , when all technology is embodied, the sign is negative, whereas at  $\lambda = 1$ , the sign is positive. But further differentiation of the right-hand side with respect to  $\lambda$  shows that it is monotonically rising in  $\lambda$ . Therefore, there is a unique  $\lambda$ , call it  $\lambda^*$ , such that at values of  $\lambda < \lambda^*$  faster growth reduces market tightness and at values of  $\lambda > \lambda^*$  it increases it. At  $\lambda = \lambda^*$  growth has no effect on  $\theta$ .<sup>13</sup>

## 2.4 Aggregation

We now aggregate the representative firm's equilibrium conditions to derive the economy's steady-state paths. Aggregate steady-state equilibrium is defined by a path for the average capital-labor ratio (derived from the optimality conditions (4), (5) and (6)), a path for the average wage rate (derived from (18) and (19)) and a stationary ratio of employment to population (derived from (33) and (24)). The exogenous variables are TFP, population and the real cost of capital.

We discuss aggregation informally, with the help of figure 1. Because of our Cobb-Douglas assumptions, the path shown for  $\phi(.,.)$  in figure 1 is a displacement of the path of the capital stock (4) and of the one for output per worker, (2), for each job. In the steady state a job is created in period 0, it is destroyed and another one created in its place in period  $T$ , which is destroyed and another one created in period  $2T$  and so on. Then, the capital stock, output and labor's marginal product from 0 to  $T$ , from  $T$  to  $2T$ , and so on grow *on average* at rate  $a$ , the slope of the broken line in figure 1, although growth for each individual job is not smooth. It is slow at first and then jumpy at the time of replacement. But if new jobs in the economy as a whole are created continually with the same frequency, which

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<sup>13</sup>Note that if  $\lambda$  is small and faster growth reduces job creation, the general equilibrium effect on  $T$  may reverse because of the dependence of  $\omega$  on  $\theta$ . In a market with poor outside opportunities existing jobs become more valuable and workers hold on to them longer, by accepting lower wages. However, the empirical analysis finds no evidence for such effects.

is an assumption that is required for a steady state, the aggregate capital stock, output and marginal product will grow smoothly at rate  $a$ . Finally, again with reference to figure 1, since the two components of the average wage rate,  $\phi(\cdot, \cdot)$  and  $\omega(\cdot)$  both grow at rate  $a$  between 0 and  $T$ , the average wage rate also grows at rate  $a$ .

Employment in the representative firm evolves on average according to the difference between job creation and job destruction. At time  $t$  this is

$$\dot{L}(t) = x(t) - e^{-sT}x(t-T) - sL(t), \quad (35)$$

where  $x(t)$  is job creation, and  $\exp(-sT)$  is the fraction of jobs of vintage  $t-T$  that survive to  $T$ , and so become obsolete. In the steady state  $\dot{L}(t)$  is equal to the rate of change of the population of working age, which we assume to be exogenous and equal to  $n$ .  $x(t)$  is given by  $\tilde{u}(t)m(\theta)$  and so it grows at  $n$ , because the number of unemployed workers  $\tilde{u}(t)$  grows at  $n$ , whereas  $\theta$  and  $T$  are the solutions to (24) and (33) and they are stationary. Steady-state unemployment is the difference between the exogenous labor force and steady-state employment. Steady-state employment is derived from (35) and satisfies,

$$nL(t) = (LF(t) - L(t))m(\theta) - e^{-(n+s)T}(LF(t) - L(t))m(\theta) - sL(t), \quad (36)$$

where  $LF(t)$  is the exogenous labor force. Solving for  $L(t)$ , we obtain:

$$L(t) = \frac{(1 - e^{-(n+s)T})m(\theta)}{(1 - e^{-(n+s)T})m(\theta) + n + s}LF(t). \quad (37)$$

When we discuss the empirical results we choose to work with the steady-state rate of unemployment, which we denote by  $u$ . It is defined as the ratio of unemployment to the labor force,  $\tilde{u}(t)/LF(t)$  :

$$u = \left(1 - \frac{L(t)}{LF(t)}\right) = \frac{n + s}{(1 - e^{-(n+s)T})m(\theta) + n + s}. \quad (38)$$

Note that the solutions to  $T$  and  $\theta$  are independent of the level of technology but its rate of growth influences employment because it influences both  $T$  and  $\theta$ .

### 3 Empirical specification

Our aim is to estimate the productivity growth effects implied by the equations for the capital stock, wages and employment. We estimate the structural equations and allow for unrestricted short-run adjustment lags by including up to two lags of the dependent variables and TFP. The steady-state

version of our model satisfies two restrictions that we impose on the estimated model and test:

1. The rate of growth of wages and the capital-labor ratio in the steady state are equal to the average rate of growth of TFP:

$$\frac{\dot{k}}{k} = \frac{\dot{w}}{w} = a. \quad (39)$$

2. Changes in the capital stock and TFP do not affect steady-state employment

$$\frac{\partial L}{\partial k} + \frac{\partial L}{\partial w} \frac{\partial w}{\partial k} = 0, \quad (40)$$

$$\frac{\partial L}{\partial A} + \frac{\partial L}{\partial w} \frac{\partial w}{\partial A} = 0. \quad (41)$$

### 3.1 The employment equation

The structural employment equation is derived from (35). The structural variables influencing job creation are derived from a log-linearized version of (33), under the assumption that job creation costs are exogenous and unobservable. These variables are the contemporaneous level of marginal product, the wage rate, the interest rate and the expected rates of growth of marginal product and the wage rate. Marginal product is proxied by its arguments, the level of TFP and the level of the capital-labor ratio, and the expected rates of growth of marginal product and the wage rate by the rate of TFP growth.

The structural equation for job destruction is derived from (24). It depends on the same variables as job creation, making it impossible to identify them separately from a single employment equation. In the absence of long time series for job creation and job destruction we have to compromise with the estimation of a single employment equation and make what inferences are possible about job creation and job destruction from it.

In the estimated employment equation the dependent variable is the ratio of employment to population of working age and the independent variables the level and rate of change of TFP, the level of the capital-labor ratio, the real cost of labor and the real interest rate. The capital stock and the real wage rate are treated as endogenous. In the short run we allow the capital stock and TFP to have different effects on employment (e.g. because the costs of adjustment in capital are different from the technology implementation lags) but in the long run their effects are restricted by (40)-(41). The

different adjustment lags in job creation and job destruction also imply differential short-run and long-run effects. Recall that TFP growth increases job destruction, by reducing the useful life of a job, but may increase or decrease job creation. Supposing that job destruction reacts faster than job creation to shocks, as usually found in the data,<sup>14</sup> we should expect the impact effect of productivity growth on employment to be negative, and either remain negative or turn positive in the medium to long run, when job creation has had time to adjust.

### 3.2 The wage equation

The structural wage equation is the aggregation of (16) with adjustment lags to pick up any short-run dynamics. We estimate an error-correction equation in wage growth and impose the restriction that real wages in the steady state grow at the rate of TFP growth. We also include the first difference in the inflation rate as an additional cyclical variable to pick up temporary deviations from the steady-state path due to information imperfections or long-term contracts. The unemployment income  $b(t)$  is represented by two parameters of the unemployment insurance system, the ratio of compensation to mean wages and the duration of entitlement. The parameter  $\beta$  stands for the share of labor in the wage bargain and it is postulated that countries with stronger unions extract a bigger share.

The other two variables in (16), the marginal product of labor and the expected returns from search are represented by the level and rate of growth of the capital-labor ratio and TFP, where now, in contrast to their effects on employment, both levels and rates of growth should have a positive impact on wages. The capital stock is divided by the labor force (rather than employment) to avoid spurious correlations due to cyclical noise in the employment series. In the steady state the unemployment rate is constant, so steady-state results are not influenced by this change.

### 3.3 The investment equation

As with the wage equation, because of the cyclicity of employment, estimating an investment equation by dividing the capital stock by employment does not give reliable results and introduces identification problems vis-a-vis the employment equation. We deal with this problem by replacing employment by the real wage and estimate an error-correction equation for the

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<sup>14</sup>The standard reference is Davies, Haltiwanger and Schuh (1996). In some European countries, however, job creation sometimes reacts faster than job destruction because of firing restrictions. See Boeri (1996).



capital stock. The long-run value of the capital stock to which the equation converges is (6), with the capital stock proportional to TFP and the factor of proportionality depending on the cost of capital and the cost of labor. For the cost of capital we use the real interest rate but we also include a variable for government debt, on the assumption that more government involvement in capital markets makes it more difficult for private business to acquire funds.<sup>15</sup>

## 4 Data and estimation

### 4.1 Data: Measuring TFP

The data are annual for the period 1965-1997 for the countries of the European Union (except for Spain and Greece), the United States and Japan.<sup>16</sup> Our data come mainly from the OECD database with some adjustments. The definitions of variables and detailed sources are given in the Appendix. The institutional variables (union density, benefit replacement ratio, benefit duration and tax wedge) are from Nickell et al. (2001) and they are available for the period 1960-1995. The Appendix describes how we calculated the capital stock and the real interest rate for each country. The other variable that we calculated is TFP growth, and we describe the procedure and results here.

We measure TFP growth by making use of a conventional growth accounting framework.<sup>17</sup> The aggregate production function is Cobb-Douglas

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<sup>15</sup>The estimated growth effects are unaffected by the inclusion of the government debt variable in the investment equation and the change in the inflation rate in the wage equation but statistically the overall fit of the equations improves because of the removal of cyclical noise. We also experimented by including other cyclical measures as independent variables, to make sure that the estimated coefficients on TFP are not dominated by cyclical effects. The other measures included the cyclical component of GDP and the deviation of hours of work from trend, for the countries with hours data. None of them influenced the estimated coefficient on TFP or its rate of growth, so we omitted them from the preferred specification.

<sup>16</sup>The European Union countries in the sample are: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Sweden and the United Kingdom. Greece was excluded because some of the institutional variables were missing and Spain because the fast rise in unemployment in the 1980s and the introduction of temporary contracts in 1984 make it an outlier for reasons unrelated to productivity growth.

<sup>17</sup>We also obtained an alternative measure of TFP with virtually no change in the results, by estimating a production function with country fixed effects and time dummies for each year in the sample.

Table 1: Growth accounting for the European Union, United States and Japan, 1965-1997

	GDP growth	Percentage contribution from		
	(%)	capital	labor	TFP
United States	2.8	37.1	43.3	19.6
European Union	2.7	36.9	6.6	56.4
Japan	4.7	53.0	13.9	33.2

with the TFP variable picking up both types of TFP of the theoretical model:

$$Y = K^\alpha(AL)^{1-\alpha} \quad (42)$$

where  $Y, K$  and  $L$  are aggregate output, capital and employment and  $A = A_1A_2$ . Converting (42) to logs, and denoting by  $d$  the change in a variable between two years, we obtain

$$(1 - \alpha)d \ln A = d \ln Y - \alpha d \ln K - (1 - \alpha)d \ln L. \quad (43)$$

As in conventional growth accounting exercises we replace  $Y, K, L$  by the measured level of GDP, capital stock and employment. But in order to obtain the rate of growth of TFP from the computed ‘‘Solow residual’’ we follow Harrigan (1997) and smooth the labor share by expressing it as a function of the capital-labor ratio and a country constant (results, however, did not differ significantly when the actual labor share was used instead):

$$(1 - \alpha)_{it} = \text{const}_i + \beta \left( \frac{K}{L} \right)_{it} + \varepsilon_{it} \quad (44)$$

with  $i$  denoting countries and  $t$  years in the sample.

Employment is measured by persons employed. In the countries that have a long time series for hours of work computed TFP growth is faster because of the fall in mean hours (especially in European countries) over the sample period. Correcting TFP for changes in hours, however, would have substantially restricted the sample because of the absence of hours data for most countries.<sup>18</sup> Table 1 reports summary results, which are as expected. Figure 2 plots the computed TFP growth for the United States, the average for the countries of the European Union and Japan. The main stylized

<sup>18</sup>See Vallanti (2004, pp. 68-71) for results with the sub-sample of countries that report hours of work. For these countries there is a correction for capital utilization and changes in hours. The estimated effects of growth on employment are, perhaps surprisingly, robust to these changes.

fact of productivity growth is fast growth in the 1960s, especially in Japan which was still undergoing reconstruction following the war, followed by a slowdown everywhere in the second half of the 1970s and a recovery in the 1990s in the United States and Europe but not in Japan. There is clear evidence of catching up with the United States in both Europe and Japan, with the exception of the 1990s, when Japanese productivity growth fell behind. Another notable feature of our computed series is that no strong cyclical pattern is evident, giving us more confidence that our estimates pick up the long-run effects that are our focus.

## 4.2 Econometric issues

The structural model is estimated by three-stage least squares. In each equation we include fixed effects for each country, and one time dummy for each year in the sample. We also include country-specific dummies for German unification.<sup>19</sup> The inclusion of lagged dependent variables can lead to finite sample biases with the within-group estimator. The results in Nickell (1981), however, show that the magnitude of the bias diminishes in the length of the time series in the panel. Since the sample runs for 31 years, the size of this bias is likely to be small. The asymptotic unbiasedness of the coefficients crucially depends on the absence of serial correlation in the errors. This will be investigated by using a serial correlation test described by Baltagi (1995).<sup>20</sup> Finally, with lags of the dependent variable included, when coefficients differ across countries, pooling across groups can give inconsistent estimates (Pesaran and Smith, 1995). We test for differences in the coefficients across the sample by using a poolability test described by Baltagi (1995).<sup>21</sup>

## 5 Estimation results

The results of the estimation are reported in Tables 2-4. The pooling restrictions on the slopes cannot be rejected at conventional levels ( $\chi_L^2(126) = 25.89$ ,  $\chi_w^2(180) = 176.69$  and  $\chi_k^2(126) = 41.36$ ). The long-run restrictions (39)-(41) are also imposed and not rejected at the 5% level, with  $\chi^2(4) = 9.60$ . The

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<sup>19</sup>The dummies for German unification are obtained by interacting the fixed effect for Germany with the time dummies for the post-unification years, 1991-95.

<sup>20</sup>The test is an *LM* statistic which tests for an *AR*(1) and/or an *MA*(1) structure in the residuals in a fixed-effects model. It is asymptotically distributed as  $N(0, 1)$  under the null. See Baltagi (1995).

<sup>21</sup>The poolability test is a generalized Chow test extended to the case of  $N$  linear regressions, which tests for the common slopes of the regressors. The test statistic is asymptotically distributed as  $\chi(q)$  under the null. See Baltagi (1995, 48-54).

time dummies remove the common employment trends and cycles in the countries of the sample and they are entered to avoid spurious correlations due to those comovements.

The estimated coefficients on the lagged dependent variables imply long lags, which we illustrate with simulations in section 5.1. In the employment equation the level of employment and the capital stock were deflated by the population of working age. This normalization gave statistically better results than the one that deflates the capital stock by the employment level, but it is isomorphic to it. The terms of the employment equation can be rearranged to yield

$$\begin{aligned} \ln(L/P)_t = & 1.21 \ln(L/P)_{t-1} - 0.27 \ln(L/P)_{t-2} - 0.059 \ln w_{t-1} - 0.076 r_t \\ & + 0.027 \ln k_t + 0.031 \ln A_t - 0.086 d \ln A_t + 0.16 d \ln A_{t-1}, \quad (45) \end{aligned}$$

where, as in the theoretical model,  $k_t$  is the ratio of capital to employment. The wage elasticity is  $-0.059$  on impact but rises to  $-1.02$  in the steady state. The interest semi-elasticity is even higher, rising to  $-1.31$  in the steady state. There are significant influences from the rate of growth of TFP on employment, which are negative in the first year but turn positive in the second. These effects are illustrated and discussed in the next two sections.

The wage equation is an error-correction equation with a long estimated adjustment lag. The key variables of the model are statistically significant and with the predicted sign. The capital stock and TFP affect the wage rate with positive coefficient, in both levels and rates of change. Unemployment has a restraining influence on wages, as predicted by the model, but its influence is reduced in countries that have long durations of benefit entitlement. This is consistent with the view often expressed in policy analyses, that long entitlement to benefit encourages the build up of long-duration unemployment, and reduces the economic role of unemployment in restraining wage demands.<sup>22</sup> This is the only parameter of the unemployment compensation system that we found statistically significant. We did not find that taxes increase wage costs but found that unionization does.

The capital stock in the wage equation is divided by the labor force instead of the level of employment to avoid the introduction of cyclical noise but of course since  $\ln L - \ln LF = \ln(1 - u) \approx -u$ , the estimated equation is approximately equivalent to an equation that has the ratio of capital to employment and three lags of the unemployment rate as independent variables. The steady-state semi-elasticity of the wage rate with respect to the unemployment rate, for a country whose unemployed lose half their entitlement after one year's unemployment, is estimated to be  $-0.04$ .

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<sup>22</sup>See, for example, Layard et al. (1991).

Table 2: The employment equation

Dependent variable $\ln(L/P)_{it}$	
Independent Variables	
$\ln(L/P)_{it-1}$	1.180 (27.12)
$\ln(L/P)_{it-2}$	-0.263 (-6.30)
$\ln w_{it-1}$	-0.057 (-4.46)
$\ln(K/P)_{it}^*$	0.027 (3.37)
$\ln A_{it}$	0.030 (3.34)
$d \ln A_{it}$	-0.084 (-3.69)
$d \ln A_{it-1}$	0.160 (7.63)
$r_{it}$	-0.074 (-2.70)
<i>Year dummies (31 years)</i>	<i>yes</i>
<i>Fixed effects (15 countries)</i>	<i>yes</i>
<i>Serial Correlation</i>	0.57
<i>p-value</i>	0.28
<i>Heteroskedasticity</i>	16.38
<i>p-value</i>	0.29
<i>Obs.</i>	462

Notes for Tables 2-4. The estimation method is three stage least squares. Numbers in brackets below the coefficients are t-statistics.  $(L/P)_{it}$  is the ratio of employment to population of working age in country  $i$  in year  $t$ ,  $(K/P)$  is the ratio of the capital stock to the population of working age,  $A$  is measured TFP progress,  $w$  is the real wage rate, and  $r$  the real interest rate. Serial Correlation is an LM test (Baltagi 1995) distributed  $N(0,1)$  under the null ( $H_0$  : no autocorrelation). Heteroskedasticity is a groupwise LM test, distributed  $\chi^2(N-1)$  under the null (given  $v_{it} = c_i + \lambda_t + \epsilon_{it}$ ,  $H_0$  :  $\epsilon_{it}$  is homoskedastic). \**Instrumented variables*: the instruments used are all the exogenous variables in the three regressions and lags of the endogenous variables.

Table 3: The wage equation

Dependent variable $d \ln w_{it}$	
Independent Variables	
$d \ln w_{it-1}$	0.058 (1.46)
$d \ln(K/LF)_{it}^*$	0.503 (4.24)
$d \ln A_{it}$	0.241 (5.89)
$\ln w_{it-1}$	-0.177 (-6.65)
$\ln(K/LF)_{it-1}$	0.083 (4.84)
$\ln A_{it-1}$	0.094 (5.45)
$\ln u_{it}^*$	-0.010 (-2.31)
$BD_{it} * \ln u_{it}^*$	0.006 (2.88)
$union_{it}$	0.043 (2.10)
$tax_{it}$	-0.055 (-0.84)
$rer_{it}$	-0.020 (-1.30)
$d^2 \ln p_{it}$	-0.203 (-3.55)
<i>Year dummies (31 years)</i>	<i>yes</i>
<i>Fixed effects (15 countries)</i>	<i>yes</i>
<i>Serial Correlation</i>	1.21
<i>p-value</i>	0.11
<i>Heteroskedasticity</i>	16.40
<i>p-value</i>	0.29
<i>Obs.</i>	462

Notes. See notes to Table 2. All variables have been defined except:  $LF$  is the labor force,  $u$  the unemployment rate,  $BD$  the maximum duration of benefit entitlement,  $union$  the fraction of workers belonging to a union (union density),  $rer$  the benefit replacement ratio,  $tax$  the tax wedge and  $p$  the price level.

Table 4: The investment equation

Dependent variable $d \ln K_{it}$	
Independent Variables	
$d \ln K_{it-1}$	0.963 (21.72)
$d \ln K_{it-2}$	-0.141 (-3.20)
$r_{it}$	-0.036 (-2.70)
$\ln w_{it}^*$	-0.012 (-1.83)
$\ln A_{it}$	0.021 (5.12)
$d \ln A_{it}$	0.064 (5.88)
$d \ln A_{it-1}$	0.026 (2.37)
$\ln(K/P)_{it-1}$	-0.009 (-2.29)
$d \ln(D/K)_{it}$	-0.005 (-2.08)
<i>Year dummies (31 years)</i>	<i>yes</i>
<i>Fixed effects (15 countries)</i>	<i>yes</i>
<i>Serial Correlation</i>	0.38
<i>p-value</i>	0.35
<i>Heteroskedasticity</i>	18.46
<i>p-value</i>	0.19
<i>Obs.</i>	462

Notes. See notes to Table 2. All variables have been defined except for  $D$ , which is the level of government debt.

As with the wage equation, the capital equation is an error-correction equation which is also characterized by a long adjustment lag. The interest rate, wage rate and growth in government debt reduce private investment. As claimed in the theoretical sections TFP and its growth rate drive capital accumulation.

## 5.1 Simulations

We report the results of two simulations to illustrate the properties of the estimated model, one showing the response of the endogenous variables to a once-for-all fall in the rate of growth of TFP and the other calculating the predicted unemployment series when TFP is given its observed values and all other exogenous variables are held fixed at their initial values. In addition to the three estimated equations we make use of the identity linking employment with unemployment,  $L_t + \tilde{u}_t \equiv LF_t$ , where as before,  $LF_t$  is the exogenous labor force in period  $t$  and  $\tilde{u}_t$  the number of unemployed people. The estimated equations are re-written in the form:

$$\begin{aligned} \ln L_t = & 1.212 \ln L_{t-1} - 0.270 \ln L_{t-2} - 0.059 \ln w_{t-1} + 0.027 \ln k_t \\ & - 0.055 \ln A_t + 0.251 \ln A_{t-1} - 0.164 \ln A_{t-2} + C_1 \end{aligned} \quad (46)$$

$$\begin{aligned} \ln w_t = & 0.881 \ln w_{t-1} - 0.058 \ln w_{t-2} + 0.503 \ln k_t - 0.420 \ln k_{t-1} \\ & + 0.241 \ln A_t - 0.147 \ln A_{t-1} - 0.010 \ln u_t + 0.503 \ln(1 - u_t) \\ & - 0.420 \ln(1 - u_{t-1}) + 0.006(\ln u_t * BD_t) + C_2 \end{aligned} \quad (47)$$

$$\begin{aligned} \ln K_t = & 1.954 \ln K_{t-1} - 1.105 \ln K_{t-2} + 0.141 \ln K_{t-3} - 0.012 \ln w_t \\ & + 0.085 \ln A_t - 0.038 \ln A_{t-1} - 0.026 \ln A_{t-2} + C_3 \end{aligned} \quad (48)$$

The  $C_i$  are ‘‘constants,’’ by which we mean all variables not varied in the simulations. The terms containing  $\ln(1 - u_t)$  in the wage equation are present because the ratio of the capital stock to the labor force in the estimated equations was replaced by the ratio of the capital stock to employment. Finally, consistency between equation (48) and the other two equations is achieved by making use of the definition  $k_t = K_t/L_t$ .

Figures 3 and 4 show the results of the first simulation. The objective is to show the impact of changes in the rate of growth of TFP on the endogenous variables but instead of assuming an arbitrary change in the rate of growth, we simulate a productivity slowdown that corresponds roughly to



Table 5: Actual and predicted unemployment rate, productivity slowdown

Period	mean TFP growth (%)		mean rate of unemployment (%)		predicted rate of unemployment (%)	
	US	EU	US	EU	US	EU
1960-73	1.90	3.95	4.96	2.26	-	-
1974-92	0.80	1.79	6.82	6.60	6.60	5.10

the slowdown observed after 1973. Table 5 shows the average TFP growth rate prior to 1973 and the average growth rate up to 1992, before growth picked up again. We initially fix TFP growth at its pre-1973 mean value (in years 1-4 in figures 3 and 4) and then reduce it to the 1974-92 mean rate, where we keep it until the end of the sample. We calibrate the constants  $C_i$  ( $i = 1, 2, 3$ ) such that all the endogenous variables are in a steady state in the 4 years preceding the shock, in which the capital-labor ratio and wage rate grow at the same rate as TFP and the unemployment rate is constant at the rate shown in Table 5. Figure 3 shows the response of wages and capital growth to the TFP shock and Figure 4 shows the response of the unemployment rate.

First, we note that both wage and capital growth eventually fall to the new level of TFP growth, but the fall is not instantaneous. Wage growth falls faster than capital growth. Wage growth covers half the distance to the new steady state in three years but the capital-labor ratio takes seven years to cover half the distance. Second, unemployment responds with a permanent rise (after a brief and small fall in the first year) but again the response is slow. Half the rise is completed after five to six years. Although there are some non-monotonic response patterns they are not strong enough to cause anything like a cycle in any of the endogenous variables (given the once-for-all exogenous change).<sup>23</sup> Third, there is a marked difference in the simulated unemployment series for the United States and Europe, due largely to the different TFP shock. TFP growth fell by more in Europe than in the United States and this accounts for a predicted rise in unemployment in Europe between 1973 and 1990 of 2.84 percentage points, in contrast to the United States, where the predicted rise is only 1.64 percentage points. Another reason for the differential response is the fact that the entitlement to unemployment benefit is longer in Europe than in the United States. As unemployment increases, the disincentive effects of the unemployment insur-

<sup>23</sup>Adjustment in the aggregate capital stock is monotonic. But because employment first rises and after one year falls, the change in the ratio of capital to employment also reverses after one year.

Table 6: Actual and predicted unemployment rate

Period	US		EU	
	unemployment (%)		unemployment (%)	
	actual	predicted	actual	predicted
1970-73	4.96	-	2.26	-
1973-79	6.40	5.90	4.13	2.87
1980-89	7.17	6.87	7.53	4.75
1990-97	6.03	5.91	8.59	4.71

ance system when the duration of entitlement is longer increase, leading to higher wages and so to higher unemployment in the countries with the longer durations. The effect of the productivity slowdown on unemployment is more than half a percentage point larger in Europe when the impact of benefit duration is taken into account. But, as Table 5 makes clear, despite the smaller slowdown in the United States, our model gets closer to attributing the full rise in US unemployment after 1973 to the slowdown, in contrast to Europe, where our prediction falls short by about 1.5 percentage points.

The predictive power of the model is shown in the second simulation, reported in Figure 5 panels (a) and (b). The figure shows the unemployment rate obtained from the model when we allow TFP growth to take its actual values but keep constant at their initial values all the other exogenous variables. Overall, the two figures indicate that our model explains a significant portion of unemployment in the two economies, though with some differences. TFP growth explains well the trend changes in unemployment in the United States. Panel (a) shows three unemployment series, the actual unemployment rate, the univariate trend unemployment rate constructed by Staiger, Stock and Watson (2002) and our simulated series. The trend unemployment rate peaks in 1980-81, in contrast to the actual rate which peaks in 1982 and our simulated rate which peaks in 1983, but despite this divergence the correlation coefficient between the trend unemployment rate and the simulated rate is 0.87. The rise up to the mid 1980s and subsequent decline are picked up by the model. But in the European Union, TFP growth explains a lower fraction of the overall change in the unemployment rate, and although the model picks up some of the rise up to the mid 1980s, it fails to account for the changes in the 1990s.

In Table 6 we report the average level of actual and predicted unemployment for three sub-periods. In 1970-73 we calibrate unemployment in the model to the observed average. In the United States, the slowdown in TFP growth after 1973 explains about 65 percent of the rise in unemployment in the 1970s but the explanatory power picks up and by the end of the sample

the model predicts a mean unemployment rate very close to the actual. In Europe the slowdown of TFP growth explains about a third of the increase in unemployment in the 1970s but it does not fully explain the further rise in unemployment that occurred in the 1980s. It predicts a flat unemployment in the 1990s, when unemployment went up by a full percentage point.

## 6 Quantitative evaluation of the model

The key result of the theoretical model is that TFP growth increases job destruction but it may increase or decrease job creation at given unemployment rate, depending on the value taken by the parameter  $\lambda$ . Given our estimate of a strong positive effect of TFP growth on employment, we investigate two issues in this section, (a) whether our estimates impose limits on the values taken by the parameter  $\lambda$ , and (b) whether a quantitative version of the model is capable of explaining the estimated impact of TFP growth on employment. The parameter  $\lambda$  stands for the fraction of new technology that is embodied in new jobs, so deriving a range for it will tell us something about the nature of new technology.

The steady-state solutions for the three unknowns,  $T$ ,  $\theta$  and  $u$ , are given by (24), (33) and (38). By differentiation with respect to  $a$  it is straightforward to show that a necessary condition for a positive impact of growth on employment is that job creation should be higher when growth is higher; i.e., that  $\partial\theta/\partial a > 0$ . The smallest value of  $\lambda$  consistent with a positive  $\partial\theta/\partial a$  is a lower bound on the values of  $\lambda$  consistent with our estimates.

From (34),  $\partial\theta/\partial a > 0$  requires

$$\lambda y'(\lambda a)\phi - y'(a)\omega > 0. \quad (49)$$

We obtain the range of  $\lambda$  that satisfies (49) when the other unknowns are at their steady-state values. Since the left side of (49) increases in  $\lambda$ , a lower bound on the values of  $\lambda$  that satisfy (49) is the  $\lambda^*$  that satisfies it with equality. The upper bound is 1. We compute  $\lambda^*$  as the solution to the following system of steady-state equations (all of which were derived in the theoretical sections)

$$\lambda^* y'(\lambda^* a)\phi - y'(a)\omega = 0. \quad (50)$$

$$y(\lambda^* a) = \frac{1 - e^{-(r+s-\lambda^* a)T}}{r + s - \lambda^* a} \quad (51)$$

$$y(a) = \frac{1 - e^{-(r+s-a)T}}{r + s - a} \quad (52)$$

Table 7: Baseline Parameter Values

$r$	0.04	$\beta$	0.50
$b$	$0.30\phi$	$\eta$	0.50
$c$	$0.10\phi$	$a$	0.02

$$T = \frac{\ln \phi - \ln \omega}{(1 - \lambda^*)a} \quad (53)$$

$$\omega = b + \frac{\beta}{1 - \beta} c\theta \quad (54)$$

$$(1 - \beta)(y(\lambda^*a)\phi - y(a)\omega) = \frac{c\theta}{m(\theta)}. \quad (55)$$

The unknowns are  $\lambda^*$ ,  $y(\lambda^*a)$ ,  $y(a)$ ,  $T$ ,  $\omega$ , and  $\theta$ . The matching flow is assumed to be constant-elasticity

$$m(\theta) = m_0\theta^\eta. \quad (56)$$

We give standard values to the parameters (shown in Table 7) except for two which are not directly observable,  $s$  and  $m_0$ , and which are obtained by calibrating them to the job destruction rate and the steady-state unemployment rate. The real rate of interest is 4 per cent per annum, the value of unemployment income is fixed at the sample mean for the United States and the hiring cost is taken from Hamermesh (1993), who estimates it on average to be one month's wages. The average recruitment cost in the model is  $c\theta/m(\theta)$ , which depends on the unknown  $\theta$ , but it turns out that  $c$  is not important in the calibration of  $\lambda^*$  (or of anything other than  $\theta$ , which is not an interesting variable in this exercise). Wages in this economy are about 94 percent of the marginal product of labor (derived below), giving the values  $0.3\phi$  for  $b$  and  $0.1\phi$  for  $c$ . The value of  $\phi$  need not be specified. The values for  $\beta$  and  $\eta$  are the ones commonly used in quantitative analyses of search equilibrium models and the value for TFP growth is its sample mean. We calibrate to US values because they are the ones that are least contaminated by policy on employment protection and other institutions that are not in the model. However, calibrating to European values gives virtually identical results.

According to Davis, Haltiwanger and Shuh (1996) the average job destruction rate in US manufacturing is 0.1 (and close to the average job destruction rate in several other countries, see their Tables 2.1 and 2.2), which implies that on average, when a firm creates a job it expects to keep it for ten years.

In our model the mean duration of jobs is given by  $(1 - \exp(-sT)) / s$ , so we treat  $s$  as an unknown and introduce the equation

$$\frac{1 - e^{-sT}}{s} = 10. \quad (57)$$

Finally, the parameter  $m_0$  is calibrated from the steady-state equation for unemployment. In our sample the mean unemployment rate in the United States is 6 per cent. We treat  $m_0$  as another unknown and introduce the equation

$$\frac{n + s}{(1 - e^{-(n+s)T}) m_0 \theta^{0.5} + n + s} = 0.06. \quad (58)$$

The value given to  $n$  turns out to be unimportant. In the model we identified it with the net rate of growth of the labor force but more generally it is the average annual rate of entry into the unemployment pool from outside the labor force. We set it equal to 0.1, which implies that the flow into unemployment from outside the labor force is approximately the same as the flow from employment.

The solutions for all unknowns are given in Table 8. The critical value for  $\lambda$  turns out to be 0.96. At this value  $\partial\theta/\partial a = 0$ , so the impact of TFP growth on employment predicted by the model is still negative. But higher values of  $\lambda$  might switch the sign to positive. Since the upper limit of  $\lambda$  is 1, the calculated value of 0.96 is a very high number. At realistic parameter values obsolescence in this model turns out to be a very powerful influence on both job creation and unemployment, and the capitalization effect turns out to be too weak an influence. In order to get a positive impact of TFP on employment we need to eliminate obsolescence with a  $\lambda$  close to its upper limit. At this high value of  $\lambda \geq 0.96$ , by the time productivity growth makes a job obsolete the job is certain to have ended for other reasons. As Table 8 shows, the solution for the maximum life of the job is so high, at 67.5 years, that with the calibrated  $s$  no jobs reach that age to become technologically obsolete.<sup>24</sup>

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<sup>24</sup>The other solution values are reasonable and need not be discussed, except for some comments about  $\theta$ , the ratio of recruitment effort to search effort. Although it is usually interpreted as the ratio of vacancies to unemployment (in which case the number 6.52 would be unreasonable) we did not give it this interpretation. We used the steady-state unemployment rate to infer it. It implies that on average the duration of unemployment in the United States is between 3 and 4 months, which is reasonable. It also implies that the average recruitment cost per employee is  $0.206\phi$ , or about 2 months' wages. This is higher than Hamermesh's estimate, but changing the parameter  $c$  in the computations by a factor of 2, which changes the recruitment cost, has no influence on the solutions for  $\lambda^*$  or  $T$  and  $s$ . It affects only the solution for  $\theta$ .

Table 8: Model Solutions

$\lambda^*$	0.96	$\theta$	6.52	$y(\lambda^*a)$	8.28
$T$	67.5	$\omega$	$0.94\phi$	$y(a)$	8.34
$s$	0.10	$m_0$	1.23		

The computed value for  $\lambda^*$  turns out to be robust virtually to all reasonable parameter variations. Increasing  $b$  to 0.6 increases  $\lambda^*$  to 0.976. Decreasing it to 0.1 reduces  $\lambda^*$  to 0.945. Increasing  $a$  to 0.05 increases  $\lambda^*$  to 0.972 and increasing it further to 0.08 increases  $\lambda^*$  to 0.988. These last two experiments are obviously too unrealistic to be for the economy as a whole but they may apply to individual sectors that are growing very fast. In the case of  $a = 0.05$  the maximum life of a job drops to 38 years and for  $a = 0.08$  it drops to 11.5 years. Finally, forcing the mean duration of jobs in the absence of obsolescence to be 4.2 years (the mean duration of a job tenure rather than the job) reduces  $\lambda^*$  to 0.942.

The reason for this robust behavior is clear from equation (50). Because the deviation between the reservation wage and marginal product in the steady state of this economy is small, the solution for  $\lambda^*$  is approximately equal to the ratio of the slopes of the present discounted value terms  $y'(\lambda a)$  and  $y'(a)$ . But the only difference between these two terms is in the discount rates  $r + s - a$  and  $r + s - \lambda a$ . The difference in these discount rates is what is sometimes called the “capitalization” effect of growth. With relatively large values for  $r + s$  (0.14 in the benchmark case) and small  $a$ , the ratio of these two expressions is approximately equal to 1.

We now turn to the quantitative evaluation of the model. Our computed range of  $\lambda$  says that virtually all new economy-wide technology is disembodied. In the steady state this leaves only the capitalization effect of growth and we investigate here whether the capitalization effect is strong enough to explain the full estimated impact.

The upper bound for  $\lambda$  is 1, when all technology is disembodied and the capitalization effect has its full impact. At  $\lambda = 1$  the equations giving the model solutions are

$$\frac{(1 - \beta)(\phi - \omega)}{r + s - a} = \frac{c\theta}{m(\theta)} \quad (59)$$

$$\omega = b + \frac{\beta}{1 - \beta}c\theta \quad (60)$$

$$u = \frac{n + s}{m(\theta) + n + s}. \quad (61)$$

The unknowns are  $\theta, \omega$  and  $u$ . We use the same parameters as before, Table 7, whereas now (57) gives  $s = 0.1$ . Rather than use an unemployment rate of 6 percent to compute  $m_0$ , we use the initial unemployment rate for the US economy in Table 5, 4.96. We then ask whether a fall in the TFP growth rate from 1.9 to 0.8 percent is capable of producing a capitalization effect that is strong enough to raise unemployment in the steady state to the value predicted by the estimates, 6.6 percent.

Our computations show that the impact of the fall in the TFP growth rate is too small to explain the estimated rise in unemployment. At the baseline parameter values unemployment rises to 4.98. Although different parameter values give slightly different values, none of them gets close to explaining the full estimated impact of the productivity slowdown. Two reasons appear to be responsible for this failure. The first is similar to the one that gave the very high values for  $\lambda^*$ . At plausible values for  $r$  and  $s$ , the observed TFP growth rates are too small to make much difference to the discount factors applied in the steady state,  $r + s - a$ . The important parameter is  $s$ , the inverse of which is the expected duration of jobs. even at 10 years on average, job durations are too short for the TFP growth rates to have much impact on job creation through capitalization.

But a second important factor that works against the capitalization effect is the sensitivity of the wage equation to the tightness of the market. When the TFP growth rate rises in this model the expected profit from job creation rises, inducing firms to increase the tightness of the market (the  $\theta$  in the model). Wages rise for two reasons, partly because of the productivity rise, and partly because of the rise in tightness. The Nash wage equation implies that the second reason is sufficiently strong to virtually offset the rise in profits associated with the rise in TFP. This discourages job creation reducing the impact of TFP growth on employment.

Recently, Shimer (2003) and Hall (2003) made a similar criticism of the Nash wage equation in the cyclical context: that it reduces substantially the variance of unemployment in response to realistic cyclical productivity shocks. The reason they give is the same as in this context, the excessive response of wages to tightness. In the remaining of this section we evaluate the impact of TFP growth on unemployment by switching off the link between tightness and wages implied by the Nash solution, i.e., adopting the “naive” wage equation,  $w = \bar{w}\phi$ , where  $\bar{w}$  is some constant between  $b$  and 1. This wage equation still reflects productivity growth and the worker’s outside income, but not the state of the labor market. It is a natural generalization of the wage equation suggested by Hall (2003) for the cyclical economy.

The equilibrium expressions under  $w = \bar{w}\phi$  become very simple. If the initial unemployment rate at some growth rate  $\bar{a}$  is denoted  $\bar{u}$ , the unem-

ployment rate at a new growth rate  $a$  is

$$u = \frac{1}{1 + \frac{1-\bar{u}}{\bar{u}} \frac{r+s-\bar{a}}{r+s-a}}. \quad (62)$$

So, if at the initial equilibrium  $\bar{a} = 1.9$  percent and  $\bar{u} = 4.96$  percent, the new  $a = 0.8$  gives  $u = 5.68$  percent. This is a substantial improvement over the impact with the full wage equation, which increased unemployment merely to 4.98. It explains about half the observed rise in unemployment. In order to match exactly the estimated impact of TFP growth with our naive wage equation we require  $r + s = 0.05$ , which is an implausibly low discount rate in the context of this model. It implies that either the rate of return to capital is extremely low, or that the expected life of a new job is extremely long. But interestingly, even at  $r + s = 0.05$ , the baseline parameters with a Nash wage equation still give only a slightly higher unemployment rate at the lower growth rate of  $u = 5.16$ .

## 7 Conclusions

In this paper we showed that although equilibrium models of employment imply that the effects of faster TFP growth can be either positive or negative, empirically the effects are strongly positive, after an initial period of not more than one year. We used our empirical estimates to obtain a prediction of the extent to which exogenous TFP growth can account for the observed changes in the rate of unemployment (or employment). The estimates do a good job in attributing the rise and fall in trend unemployment in the United States to the 1973 productivity slowdown and its subsequent recovery. The estimates also attribute a substantial part of the rise in the European unemployment rate to a productivity slowdown but empirically productivity changes are generally less successful in explaining the dynamics of European unemployment.

Our theoretical model is a perfect foresight model of job creation and job destruction and so the impact of TFP growth on employment is derived from the response of firms to changes in their implicit discount rates (the “capitalization” effect) and to obsolescence (the “creative destruction” effect). The net effect of TFP growth on employment in this framework depends critically on the fraction of TFP growth that is embodied in new jobs. Our empirical estimates imply that all new technology is disembodied and “creative destruction” plays no part in the steady state employment dynamics of the countries in our sample.<sup>25</sup>

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<sup>25</sup>It should be reiterated that our test was for technology embodied in new jobs, not



But we also found that even with no creative destruction effect, the capitalization effect of faster growth is quantitatively too small to explain the estimated impact of growth on employment. Assuming a more naive wage equation than the Nash sharing rule, whereby wages reflect productivity but not labor market tightness, increases substantially the calculated impact of growth on unemployment, although about half the estimated impact is still unexplained. Thus, the full size of the estimated impact of growth on unemployment remains a puzzle. It could mean that there are additional forces at work contributing to a positive relation between productivity growth and employment, beyond the capitalization effect. Such forces could be related to the labor supply forces identified by Phelps (1994), Hoon and Phelps (1997) and Ball and Moffitt (2002), which, although temporary, imply long lags in the effect of growth on employment.<sup>26</sup> More work is needed in linking the demand-side factors modeled here and the supply-side factors modeled by others. There could also be other forces at work. The estimated impact of TFP growth on employment at the aggregate level is certainly sufficiently large to warrant more work, both theoretical and empirical.

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in new capital, and it is consistent with any fraction of embodiment in new capital. For example, Hornstein et al. (2002) claim that a model with a large fraction of embodied technology can explain some labor market facts. Our respective claims are not inconsistent with each other because we test for embodiment in new jobs whereas they test for embodiment in new capital.

<sup>26</sup>In Phelps’ work, the impact is due to the fact that a change in the productivity growth rate changes the ratio of income from human capital to income from wealth. The supply of labor adjusts (up when the rate of productivity growth rises and down otherwise) until the ratio is restored, which could take many years. In Ball and Moffitt workers misperceive the change in the rate of TFP growth. They claim that it takes many years to adjust perceptions of future wage growth.

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## 8 Appendix: Data definitions and sources

- $L$  Total employment (*source*: OECD National Accounts).
- $P$  Working age population (*source*: OECD National Accounts).
- $LF$  Labor force (*source*: OECD National Accounts).
- $w$  Real labor cost:  $w = \left( \frac{WSSE}{def_{GDP}} \right) / (L - L_{self})$ , where WSSE is the compensation of employees at current price and national currencies (*source*: OECD Economic Outlook),  $def_{GDP}$  is the GDP deflator, base year 1990 (*source*: OECD National Accounts),  $L$  is total employment and  $L_{self}$  is the total number of self-employed (*source*: OECD National Accounts).
- $K$  Real capital stock. The calculation of the capital stock is made according to the Perpetual Inventory Method:  $K = (1 - \delta)K_{-1} + \left( \frac{I^n}{def_{INV}} \right)_{-1}$ , where  $I^n$  is the gross fixed capital formation at current prices and national currencies (*source*: OECD National Accounts) and  $def_{INV}$  is the gross fixed capital formation price index, base year 1990 (*source*: OECD National Accounts) and the depreciation rate,  $\delta$ , is assumed constant and equal to 8 percent, which is consistent with OECD estimates (Machin and Van Reenen, 1998). Initial capital stock is calculate as:  $K_0 = \frac{I_0}{g + \delta}$ , where  $g$  is the average annual growth of investment expenditure and  $I_0$  is investment expenditure in the first year for which data on investment expenditure are available.
- $A$  Total factor productivity (TFP). This is computed using the following formula:  $d \ln A = \frac{1}{1 - \bar{\alpha}} [d \ln Y - \bar{\alpha} d \ln K - (1 - \bar{\alpha}) d \ln L]$ , where  $Y$  is gross domestic output at constant price and national currencies (*source*: OECD National Accounts),  $K$  is capital stock as defined above,  $L$  is total employment as defined above,  $(1 - \bar{\alpha})$  is a smoothed share of labor following the procedure described in Harrigan (1997). Labor share is defined as  $(1 - \alpha) = \frac{wL}{Y}$ . In order to make our measure of total factor productivity comparable across countries, we convert both  $Y$  and  $K$  to US dollars using the GDP and gross fixed capital formation Purchasing Power Parities (1990) respectively (*source*: OECD National Accounts).

- r* Real long term interest rate deflated by the 3-year expected inflation rate:  $r = i - E(d \ln p_{+1})$ , where  $i$  is the long term nominal interest rate (*source*: OECD Economic Outlook).  $E(d \ln p_{+1})$  are fitted values from the regression  $d \ln p = \gamma_1 d \ln p_{-1} + \gamma_2 d \ln p_{-2} + \gamma_3 d \ln p_{-3} + \nu$ , where  $d \ln p$  is the inflation rate based on the consumer price index  $p$  (*source*: OECD National Accounts) and the coefficients on the right side are restricted to sum to one, indicating inflation neutrality in the long run (see Cristini, 1999).
- u* Unemployment rate:  $u = 1 - \frac{L}{LF}$ , where  $L$  is the total employment and  $LF$  is the total labour force (see above for definition and data sources).
- union* Net union density defined as the percentage of employees who are union members (*source*: Nickell et al. 2001).
- tax* Tax wedge calculated as the sum of the employment tax rate, the direct tax rate and the indirect tax rate (*source*: Nickell et al. 2001).
- rer* Benefit replacement ratio defined as the ratio of unemployment benefits to wages for a number of representative types (*source*: Nickell et al. 2001, constructed from OECD data sources).
- BD* Benefit duration defined as a weighted average of benefits received during the second, third, fourth and fifth year of unemployment divided by the benefits in the first year of unemployment (*source*: Nickell et al. 2001, constructed from OECD data sources).
- p* Consumer price index, base year 1990 (OECD, Main Economic Indicators).
- D* Gross government debt (*source*: OECD Economic Outlook and for UK IMF International Financial Statistics) divided by the GDP deflator. For missing values before 1970, debt is calculated using the formula:  $D - D_{-1} = DF$ , where  $DF$  is the government deficit (*source*: IMF International Financial Statistics).

Figure 1  
Expected returns and costs from job creation

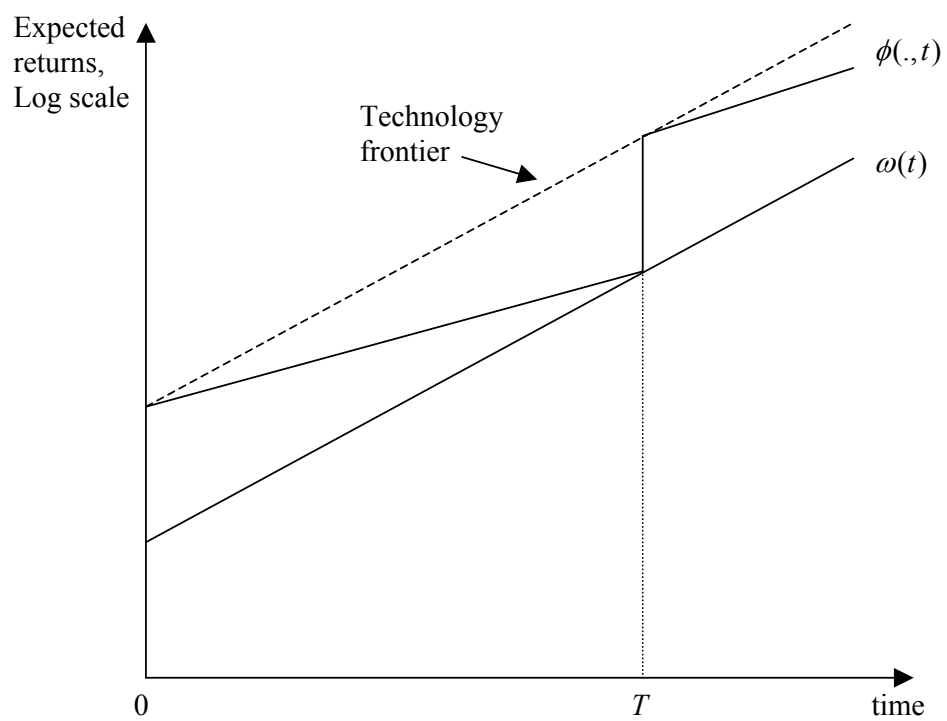


Figure 2

Total Factor Productivity in the United States, European Union and Japan, 1965-1997

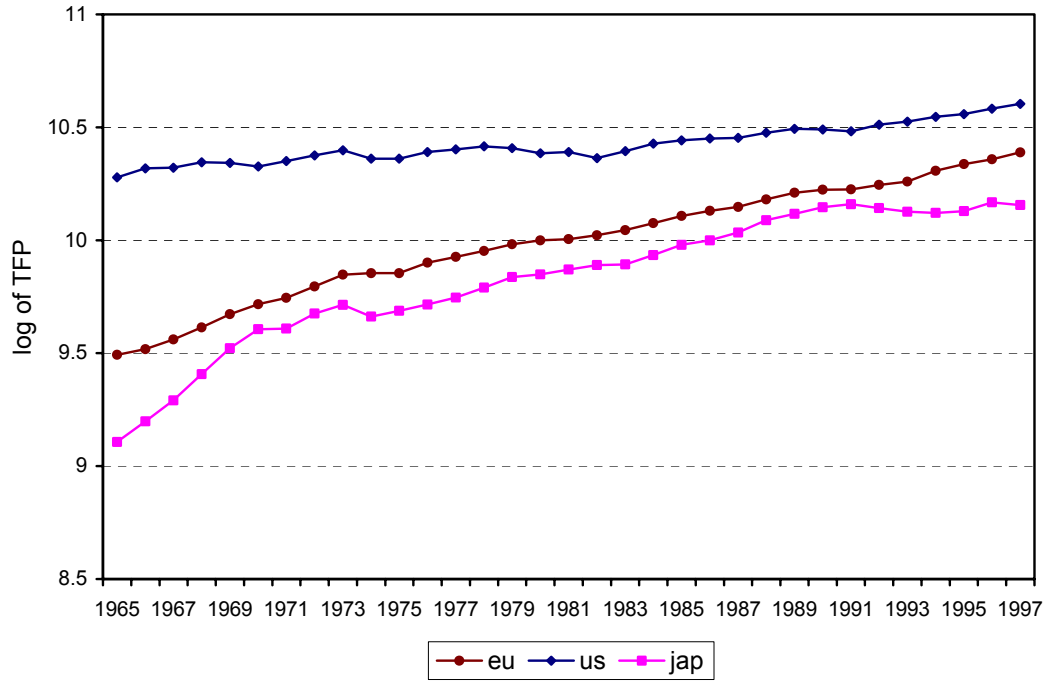
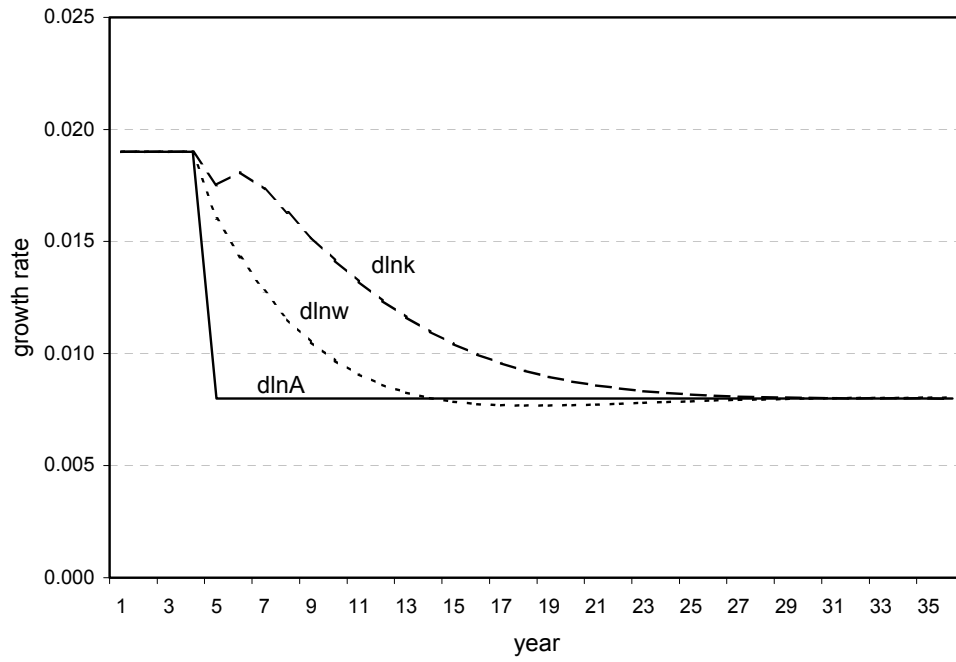


Figure 3

Growth rates of TFP, wages and the capital-employment ratio following the 1973 slowdown

(a) United States



(b) European Union

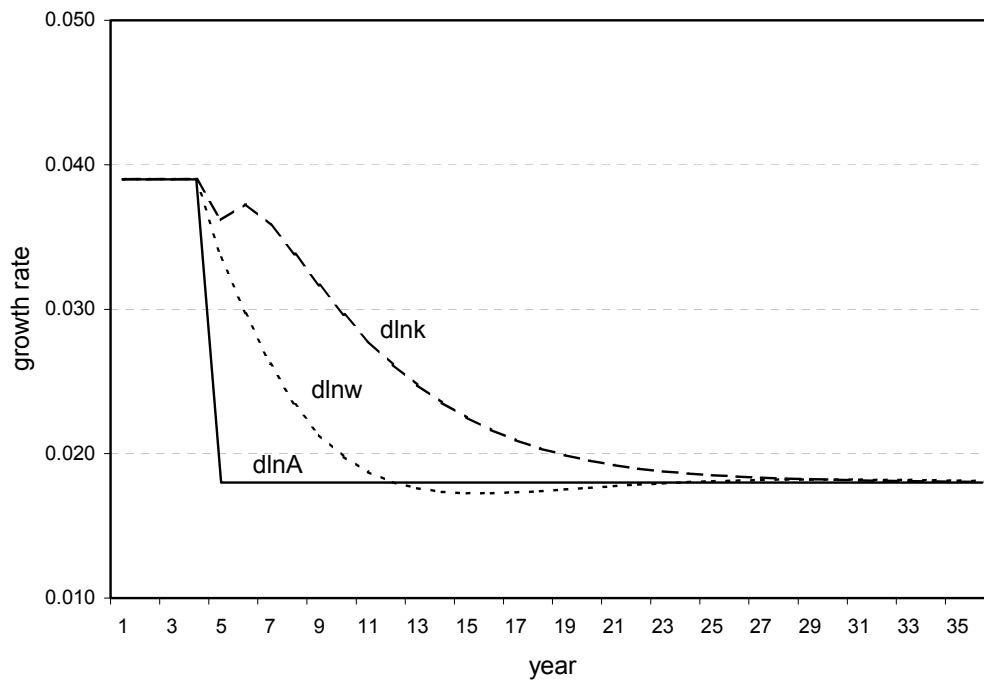




Figure 4

Predicted unemployment response to the 1973 productivity slowdown

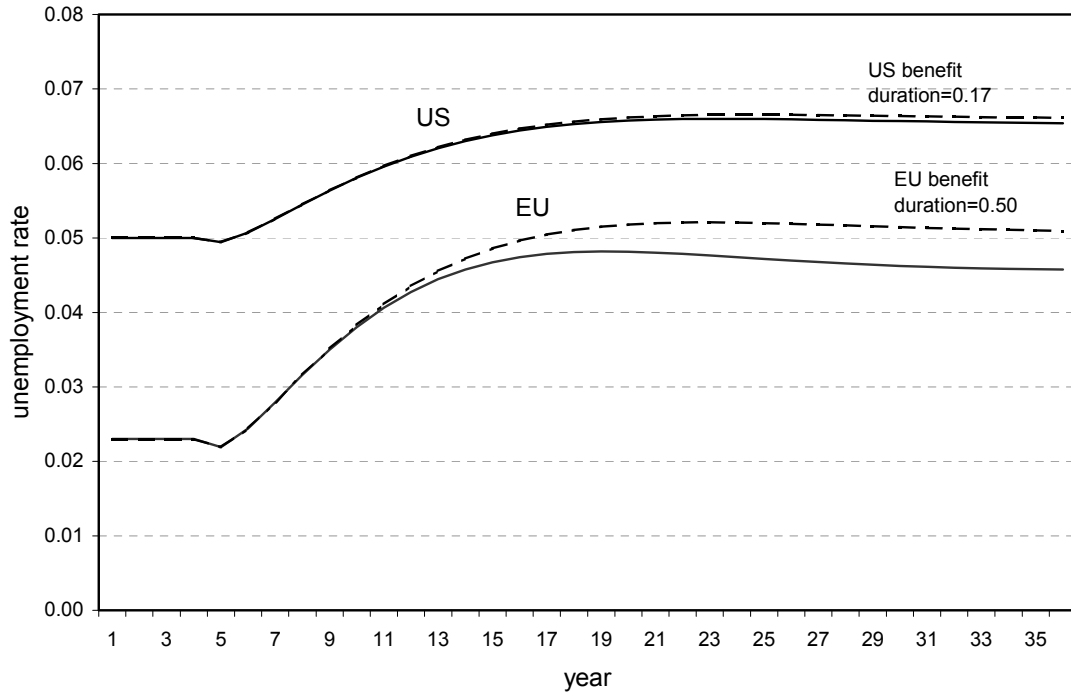
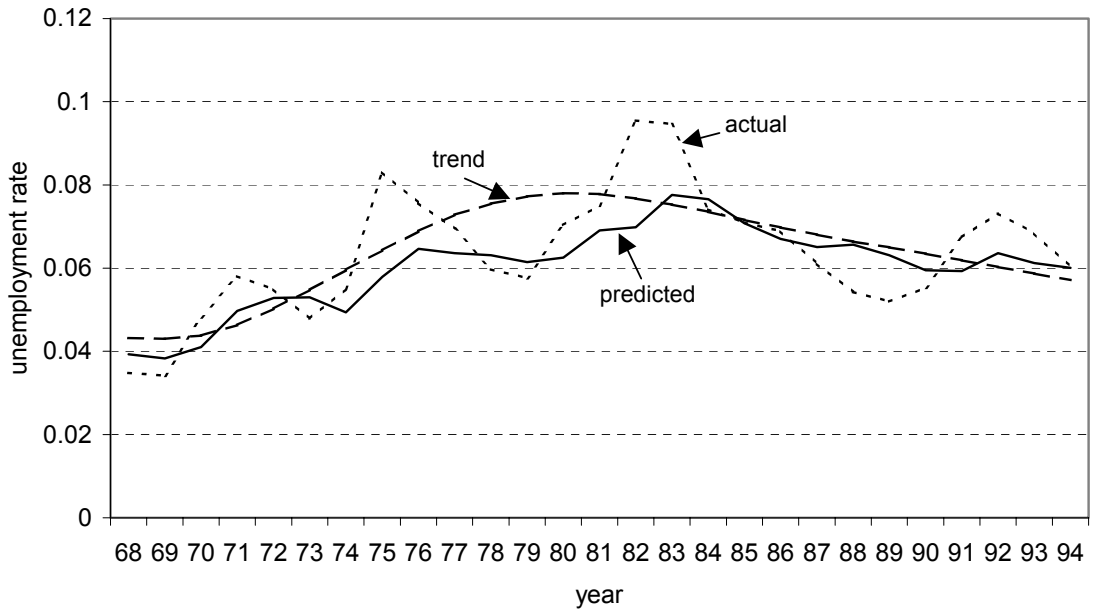


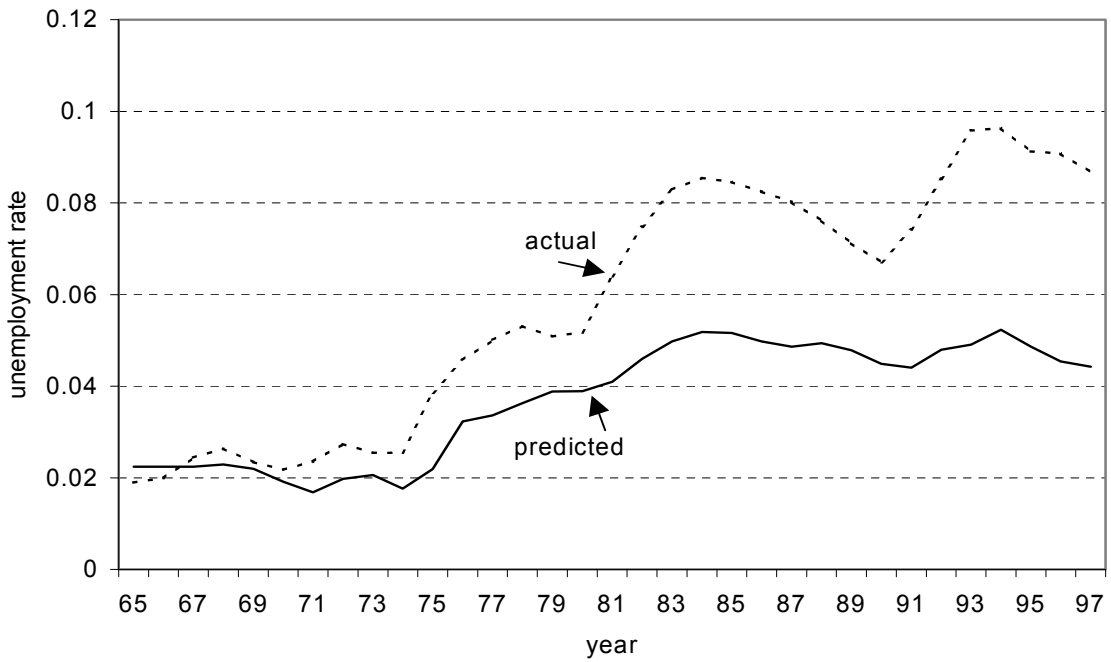
Figure 5

Comparison between the actual and predicted unemployment rate when TFP takes its actual values and all other exogenous variables are held constant

(a) United States



(b) European Union



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