Does Employment Protection Inhibit Technology Diffusion?

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February 2004

Abstract

I ask whether differences in labor market performance between the US and Europe can be attributed to an interaction between employment protection legislation (EPL) and an acceleration in the rate of capital-embodied technical change associated with the advent of information technologies.

I find that EPL is associated with a slowing in the diffusion of new technologies. I also find that an acceleration in the rate of embodied technical change has a negligible effect on employment in an undistorted economy. In addition, in the presence of EPL, employment decreases in the long run after such a shock.

JEL Codes: E6, J21, J63, J65, L63, L86, O33, O38

Keywords: embodiment, vintage capital, dismissal costs, employment, information technology.

1 Introduction

Is there a link between employment protection legislation (EPL) and the rate of technical change?

An extensive literature studies differences in labor market performance between the US and Europe in recent decades. Many accounts of these differences have centered upon differences in labor market institutions. A notable contribution is that of Ljungqvist and Sargent (1998), who argue that a combination of job security and unemployment policies could have left many European economies vulnerable to a period of "turbulence" that arrived in the 1970s and 1980s.

There is an independent literature that studies the nature of capital-embodied technical change. This literature generally finds that the rate of embodied technical change accelerated

*Thanks are due to Boyan Jovanovic, Samuel Pessoa, Rafael Rob, Richard Rogerson, Randy Wright, and participants at the Society for Economic Dynamics 2001 Annual Meetings at the Stockholm School of Economics and the Society for the Advancement of Economic Theory 2003 Annual Meetings in Rodos for their suggestions and insights. All errors are the author's. An earlier draft circulated under the title "Regulation and the Diffusion of New Technologies." Correspondence and comments: Roberto M Samaniego, 2201 G St. NW #624, Washington, DC 20052. Tel: (202) 994-6153. Fax: (202) 994-6147. E-mail: roberto@gwu.edu

starting in the mid 1970s.[1] Other authors have associated this phenomenon, as well as subsequent asset price and macroeconomic dynamics, with the sudden and wide diffusion of Information Technology[2] (IT). For instance, Gordon (1990) and Cummins and Violante (2001) show that IT is the industry in which embodied technical change proceeds at the fastest pace.

In this paper, I ask whether a contributing factor to the European employment dilemma could have been an interaction between the acceleration of embodied technical change associated with the spread of IT on the one hand, and labor market ridigities on the other.

First, I develop a general equilibrium framework that is suited to studying the relationship between regulation and the vintage distribution. I find that, in the model, EPL is associated with decreases in employment. Moreover, these decreases are larger when capital embodied technical change is faster. I also find that EPL is associated with the somewhat slower diffusion of technology, as reflected in the vintage distribution.

An acceleration of embodied technical change has two effects that could interact with dismissal costs. First, the rate of embodied technical change might be negatively related to the average scale of production, because productivity and hence optimal plant size decline together at a rate that depends on the pace of technical change – see Mitchell (2002). A likely consequence of this is that, in economies where the cost of dismissing workers is high, hiring will be suppressed as a result of the fact that the optimal firm size declines faster, and a given job is likely to be destroyed sooner, when technical change is rapid. I call this the acceleration effect. Second, if all other fundamentals remain the same, an acceleration in the rate of embodied technical change may also constitute an increase in "turbulence," increasing the *variability* of optimal plant size. Interestingly, I find that the quantitative impact of the acceleration effect appears to be more important than the turbulence effect.

Section 2 introduces the theoretical model. Section 3 characterizes the plant's problem, solution, and macroeconomic equilibrium. Section 4 describes the calibration procedure, while Section 5 studies the relationship between EPL and technical change. Section 6 discusses findings and extensions.

2 Model Economy

First, I provide a brief overview of the structure of the model, along with an overview of its relationship to related frameworks.

The economy is a vintage capital model characterized by ongoing job and establishment turnover. Reallocation of resources across plants will be a precondition for ongoing growth, so that the adoption of new capital and the eventual abandonment of the old are essential features. Reallocation will also be partly due to idiosyncratic factors at the plant-level, reflecting the wide outcome heterogeneity documented among plants that are otherwise observationally equivalent. Adoption may take place either through investment at old plants or through the creation of new ones. The model thus contains the minimum of ingredients necessary to address the relationship

[1] See McHugh and Lane (1987), Greenwood et al (1997), Cummins and Violante (2001) and Samaniego (2004b). Strictly speaking these papers focus on investment-specific technical change. In a slight abuse of terminology, in what follows I use the terms "investment-specific technical change" and "capital-embodied technical change" interchangeably.

[2] See for example Hobijn and Jovanovic (2001).

between technical diffusion and regulation.

The model economy combines elements of Hopenhayn (1990) and Mitchell (2002). The applied literature on employment protection often uses general equilibrium versions of Hopenhayn (1992). Mitchell (2002) develops a vintage capital model that is consistent with data on the rate of technical change and the scale of production. In that model, however, exit is exogenous and there is no possibility of improving technology at a plant. Instead, I allow for technical change to occur through "updating" as well as entry. I also endogenize exit in the manner of Samaniego (2004a). This is necessary for the lifetime of capital to be endogenous. I provide a relatively brief description of the model: the interested reader is referred to Samaniego (2003) for further details.

2.1 Establishments

There is a continuum of heterogeneous plants of endogenous mass that course through discrete time. Plant output is determined partly by the age of its capital, and partly by chance. Heuristically, an existing plant has three decisions to make:

1. how much labor to hire;
2. whether or not to close;
3. whether or not to "update" the technology it is using.

2.1.1 Output

At any point in time t a plant is characterized by the vintage $t-\tau$ of the technology it embodies (hence τ is its age), by an idiosyncratic productivity shock $z_t \in [0, \overline{z}]$, and by its labor input n_t, for which it pays a wage w_t. Its production function is

$$\gamma_D^t \gamma_E^{t-\tau} z_t n_t^\theta,$$

where γ_D is an exogenous *disembodied* productivity growth factor and γ_E is an exogenous *embodied* productivity growth factor. Parameters γ_D and γ_E distinguish between two types of technical change. Each period, the productivity of all plants in operation improves by a factor γ_D. On the other hand, the productivity of *new* plants improves by a factor γ_E also. Existing plants do not benefit from this latter mode of technological progress, unless they invest in updating their capital. Idiosyncratic productivity is governed by a Markov process generated by a distribution $f(z_{t+1}|z_t)$.

There is one unit of capital per plant. I concentrate on the extensive rather than the intensive margin for three main reasons:

1. Most investment occurs in "lumps". With the intensive margin of capital, these lumps would be timed to coincide with instances of updating, as in Samaniego (2003a).
2. The model isolates the effect of policy through the replacement channel

3. I do not need to address the issue of whether productivity is embodied in capital, or whether there is a complementarity between capital- and establishment-level embodiment – see Nelson and Winter (1982). Samaniego (2003b) finds that taking a stance on one or the other approach leads to similar values for γ_E, so this agnosticism is also useful for purposes of calibration.

Another interpretation of the model is that there is a representative firm, and that each plant is in fact a unit of capital used by the firm. z_t then captures how well or badly this unit performs in a particular period. This interpretation places the model closer to the model of Campbell (1998) – except that I allow for the possibility of updating.

2.1.2 Updating

At the end of each period, plants have the option of upgrading their capital to any level below the frontier productivity next period.[3] If an establishment desires to attain a level of productivity $\pi \leq 1$ relative to the frontier, it must incur a cost $\kappa \pi p_t$. κ is a technological parameter, whereas p_t is the price of an intermediate or "managerial" good. This structure is simple in that the cost of updating only depends on the target vintage: if the target productivity is $\gamma_E^{t-\tau'}$, the associated cost is $\kappa \frac{\gamma_E^{t-\tau'}}{\gamma_E^t} p_t = \kappa \gamma_E^{-\tau'} p_t$.

2.1.3 Closings

Plant closure will be one important reason for the retirement of capital, so that matching shutdown rates carefully will be important for the calibration procedure. Hence, I require a non-trivial model of shutdowns.

Every period, establishments are subject to a number of possible, mutually exclusive shocks aside from their productivity shock. These are uncertain payments that they must make that are not directly related to productivity itself, and may be thought of as including any fixed costs of operation as well as other shocks such as legal problems, plant breakdowns, strikes, fires, etc. I term these "continuation shocks". Payments all involve purchasing an appropriate number of units of the intermediate good.[4]

There is a set Φ of possible such payments. Let J be the cardinality of Φ, so that any particular payment value ϕ_j is indexed by $j < J$, ordered without loss of generality so that $i < j \Longleftrightarrow \phi_i < \phi_j$. With each ϕ_j I associate a probability λ_j, where $\sum_{\phi_j \in \Phi} \lambda_j = 1$. The cost is paid in terms of the managerial good. Thus, the inputs used to establish them are the same as those used to keep them running.

[3] In principle they may also "downgrade" their capital; however, the proof of Proposition 2 shows that this will never be optimal.

[4] The fact that continuation costs as well as the updating cost depend on a price allows the model to exhibit stationarity, as costs can maintain their magnitude *relative to output* on a balanced growth path. This obviates the need to include a fixed cost that increases exogenously. Another option would be, as in Campbell (1998), to consider an exogenous scrap value per efficiency unit of retiring plants. I abstract from scrap values as, in terms of calibration, scrap values and costs of this type play similar roles, and hence they will not affect results.

Other models either impose exogenous closure or imply that costs such as ϕ increase exogenously over time. The former does not account adequately for differential hazard rates among cohorts. The latter lacks an economic foundation.

At the beginning of each period, before the realization of z_t, an establishment draws some ϕ_j from Φ, and must pay $\phi_j p_t$ in order to continue in operation – where draws are independently distributed across establishments and over time. Plants whose continuation value is lower than $\phi_j p_t$ may optimally choose to close.

Again, there are many interpretations of the continuation shock. It could represent any of the aforementioned unforeseen shocks. It could also capture exogenous variations in financial constraints the establishment faces. It could also represent changes in technology, such as "re-organization shocks" – accumulated organizational capital in the relevant industry may become obsolete due to *qualitative* changes in technology that require different and unfamiliar methods for implementation or use, and payments to consultants are necessary for effective continuation.

An advantage to this framework is that it includes many alternative structures as special cases. For instance, Hopenhayn and Rogerson (1993) assume that there is a per-period cost to remaining in operation. In the present framework, this is equivalent to setting $J = 1, 0 < \phi_1 < \infty, \lambda_1 = 1$. However, this formulation implies counterfactually that exit is highly concentrated among the youngest establishments.

Hopenhayn and Rogerson (1993) is calibrated to quinquennial data. If the model were annual or quarterly, the implied differences between model behavior and the data would be significant, with almost all exit occurring in the first period of life. An alternative when using shorter periods is to impose the exogeneity of establishment exit, as in Veracierto (2001). This is equivalent to setting $J = 2, \phi_1 = 0, \phi_2 = \infty, \lambda_2 < 1$. However, when the endogenous response of plant closure may be an important determinant of aggregate dynamics, exogeneity eliminates a critical margin.

By setting $J \geq 2$ and allowing the various shock values to be determined by the calibration process enables the allocation of a differing role of shutdowns in job destruction across age groups. In particular, it may be that $\phi_1 = 0$ so that some plants of all types will be able to persist, whereas ϕ_J is so costly that no firm regardless of productivity can survive and, to this extent, exit is indeed exogenous. To the degree that exit is driven by either of these shocks, the exit margin will not be directly affected by policy. To the degree that it *is* driven by other shocks, it may. I make the assumption henceforth that $\phi_J = \infty$.

2.1.4 Newcomers and the Managerial Good

The intermediate managerial good is produced by households, using labor as the only input. It has three uses: to maintain plants in operation, to generate new plants, and for updating. New plants begin operations in the period following their inception.

If household i spends m_{it} hours producing the managerial good, the resulting output is given by a production function $\zeta(m_{it})$. I assume $\zeta' > 0, \zeta'' < 0$.

As noted, entering plants adopt the newest vintage when they begin operations[5]. At that point, each receives its initial idiosyncratic shock z from a distribution $\psi(z)$ and must produce for at least one period. Hence the entry decision is made prior to the revelation of z.

An establishment's "type" is a pair (τ, z_t). Let $\mu_t : \mathbb{R} \times \mathbb{N} \rightarrow \mathbb{R}$ be the measure over types, and let E_t be the mass of entering plants at date t. The evolution of the measure over types follows a transition function G, so that $\mu_{t+1} = G(\mu_t, E_t)$. G is an equilibrium object in that it

[5] Endogenous growth extensions of the model that oblige plants to buy their initial capital for a vintage-contingent price have all plants adopting the frontier technology in equilibrium.

must be consistent with the various optimal decision rules, satisfying a functional equation that is described in Appendix C along with an algorithm for its computation.

2.2 Households

There is a continuum of infinitely lived dynastic households that grow each period by a factor ν. Preferences over streams of consumption $\{c_t\}_{t=0}^{\infty}$ and leisure $\{l_t\}_{t=0}^{\infty}$ take the form

$$E\sum_{t=0}^{\infty}\beta^t\nu^t\left[\log c_t + L(l_t)\right]$$
$$l_t \in [0,\omega], c_t \geq 0 \forall t$$

where ω is their individual time endowment.

Households are involved in several activities. They supply labor to a competitive market, and spend time creating the managerial good as above, which also trades on a competitive market. Finally, using the income they derive from the above activities and the assets they already own, they purchase new assets (plants) and consumption goods. The price of the consumer good is normalized to equal one in each period. The per-period household recursive problem then becomes:

$$H\left(\widehat{\mu}_t\right) = \max_{c_t,e_t,h_t,m_t}\left\{\log c_t + L\left(l_t\right) + \beta\nu H\left(\widehat{\mu}_{t+1}\right)\right\}$$

subject to

$$\begin{aligned} c_t + p_t e_t &\leq \Pi\left(\widehat{\mu}_t\right) + w_t h_t + p_t\zeta(m_t) \\ l_t &= \omega - h_t - m_t \\ \widehat{\mu}_{t+1} &= G\left(\widehat{\mu}_t, e_t\right) \end{aligned}$$

where

$$\begin{aligned} p_t &= \text{price of the managerial good} \\ m_t &= \text{hours spent creating the managerial good} \\ h_t &= \text{hours spent working} \\ \Pi\left(\widehat{\mu}_t\right) &= \text{income from currently owned assets (plants)} \\ e_t &= \text{purchases of new assets} \\ \widehat{\mu}_t &= \text{the measure of the household's asset holdings} \end{aligned}$$

That people – particularly those with managerial experience – switch between labor markets and entrepreneurialism is documented in Lazear (2002). Symmetry of ownership across households is assumed.[6] The fact that agents must be indifferent between labor and entrepreneurialism in equilibrium will play the role of a free-entry condition.

[6] In any stationary equilibrium, $\mu_t = \hat{\mu}_t$. Symmetry is a natural assumption since, at the time of asset purchase, a household cannot tell what its realized dividends will be. Moreover, consumer heterogeneity is not the focus of study.

3 Stationary Equilibrium

As specified, the economy is non-stationary due to the presence of exogenous growth. However, there exists a transformation of the economy *a-la* King *et al* (1987) that allows the application of standard recursive solution methods. Let $\gamma = \gamma_E \gamma_D$. The paper will focus on a balanced growth path in which there are numbers c, E, h, m, Π, w, p and a measures μ such that

$$\begin{aligned}
c_t &= \gamma^t c \\
E_t &= \nu^t E \\
p_t &= \gamma^t p \\
h_t &= h \\
m_t &= m \\
w_t &= \gamma^t w \\
p_t &= \gamma^t p \\
\mu_t &= \nu^t \mu \\
\Pi(\mu_t) &= \gamma^t \Pi
\end{aligned}$$

Hence, we can redefine the variables in question with respect this path. For simplicity, I continue the discussion assuming that the economy is on this path.

Relative to the frontier, the productivity of a plant's capital decreases at the rate of embodied technological progress. This is broadly in line with the findings of Bahk and Gort (1993), in which annual differences in average capital age are measured to correspond on average to decreases in plant level productivity of several percentage points net of other factors.

Timing is as follows. At the beginning of each period, plants observe the value of z_t and produce. At the end of the period, they draw $j \leq J$ and decide whether or not to continue into the following period. If they do not, they exit. If they do, then they also choose whether or not to update their capital to a different vintage.

Let W be the value function of the plant. Define also C as the plant's continuation value at the end of each period, and U as the value of updating. Then,

$$C(\phi_j, \tau, z_t) = \max\left\{0, U(z_t) - \phi_j p_t, E_{z_{t+1}} W(\tau+1, z_{t+1}) - \phi_j p_t\right\} \tag{1}$$

$$U(z_t) = \max_{\tau' \leq \tau}\left\{E_{z_{t+1}} W(\tau', z_{t+1}) - \kappa \gamma_E^{-\tau'} p_t\right\} \tag{2}$$

$$W(\tau, z_t) = \max_n \left\{\gamma_E^{-\tau} z_t n^\theta - w_t n + \frac{\gamma}{1+i} \sum_j \lambda_j C(\phi_j, \tau, z_t)\right\} \tag{3}$$

Let Υ be the optimal updating rule and X be the plants' optimal shut-down rule, defined as follows:[7]

$$\begin{aligned}\Upsilon\left(\tau,z_t\right) &= \arg\max_{y\in[0,1]} yU\left(z_t\right)+\left(1-y\right)E_{z_{t+1}}W\left(\tau+1,z_t\right)\\ X\left(\phi_j,\tau,z_t\right) &= \arg\max_{x\in[0,1]} x\cdot\left[\Upsilon\left(\tau,z_t\right)U\left(z_t\right)+\left(1-\Upsilon\left(\tau,z_t\right)\right)E_{z_{t+1}}W\left(\tau+1,z_t\right)-\phi_j p_t\right]\end{aligned}$$

3.1 The (S,s) Structure of Updating

The following statements characterize the structure of exit and updating in the steady state of this economy. They will prove useful in deriving the equilibrium transition function G, and in forming an algorithm to compute the steady state measure. In what follows I make a stochastic dominance assumption about f that endows W and X with a number of intuitive properties, for given w, p and G. Proofs are provided in the Appendix.

Condition 1 The process generated by f is stationary.

Condition 2 $\int_{-\infty}^{Z} f(z_{t+1}|z_t)dz_{t+1}$ is weakly decreasing in $z_t \forall Z$.

Condition 1 is required for W to be finite, and is assumed throughout. Condition 2 delivers monotonicity of closure and updating rules.

Lemma 1 The plant's value function exists, is unique, is strictly decreasing and strictly convex in plant age τ.

Lemma 2 Assume Condition 2 holds. Then W is strictly increasing in z.

Proposition 1 If a plant with individual state (τ, z_t) updates, then one with (τ', z_t), $\tau' > \tau$ does also.

Proposition 2 All updating is to the frontier.

These propositions can be proven, *mutatis mutandis*, for the distorted economy below. In combination, Propositions 1 and 2 characterize the plant's updating rule as being of the (S, s) form, conditional on z and censored by the optimal exit rule - see Figure (**??**).

Proposition 3 Assume Condition 2 holds. If a plant of type (τ, z_t) prefers to update, one of type (τ, z_t') does so too for $z_t' > z_t$.

Proposition 4 The exit rule is increasing in τ, and decreasing in z.

Plant closures generally take place among the least productive. If productivity is low because the plant is old but z_t is high, it is likely to update rather than close. If the plant is young but z_t is low, however, it is more likely to close. Thus the model can accommodate a wide variety of plant dynamics. For example, some leapfrogging may occur when plants update, but not necessarily much.

[7] At this point the equation for profits can be written explicitly as

$$\Pi\left(\hat{\mu}_t\right)=\int z_t\gamma_E^{t-\tau}\gamma_D^t n_t^\theta - w_t n_t - \Upsilon\left(\tau,z_t\right)\kappa p_t - \sum_j \lambda_j\left[\left(1-X\left(\phi_j,\tau,z_t\right)\right)\phi_j p_t\right]d\hat{\mu}_t$$

3.2 Equilibrium

Definition A *stationary equilibrium* is a list of functions for plants W, C, U, Υ, X, n; for households H, c, e, m, h; aggregate functions E, w, p and a measure μ such that the following conditions are satisfied:

i) plant optimality: W is the plant's value function, yielding n, Υ and X as optimal decision rules;

ii) Household optimality: H is the household's value function, yielding c, e, m and h as decision rules;[8]

iii) Product market clearing: $c = \int \gamma_E^{-\tau} zn(\tau, z)^{\theta} d\mu$;

iv) Labor market clearing: $h = \int n(\tau, z; \mu) d\mu$, where n is the optimal labor input level for the plant.

v) Managerial good market clearing:

$$\sum_j \left(1 - \int X\left(\phi_j, \tau, z\right) d\mu\right) + \kappa \int \Upsilon\left(\tau, z\right) d\mu + E_t = \zeta\left(m\right)$$

vi) Consistency in entry: $E = e$;

vii) Stationarity of μ: $\mu = \frac{1}{\nu} G(\mu, E)$.

viii) Symmetry: $\mu = \hat{\mu}$.

While an existence proof for this model is intractable, it is worth commenting on the subject. Models with heterogeneous establishments generally require a condition on the income effect of labor supply to guarantee existence,[9] and cannot necessarily guarantee that entry and exit will exist in equilibrium. In this environment, if $\lim_{m_+ \to 0} \zeta'(m) = \infty$, there *must* be entry in equilibrium. Some entry will always be profitable, given that the continuation costs ϕ_j do not have to be paid. To see this, observe that even if $J = 1$ and $\phi_1 = \infty$, a "fly-by-night" equilibrium in which plants operate for one period only could still exist. Also, given that $\gamma_E > 1$, for any w there will be *some* exit even if $\phi_J < \infty$. Hence, any stationary equilibrium will have both entry and exit in this environment.

4 Calibration

Period length is considered to be 1 year. There is extensive documentation of the fact that the environment faced by young plants, particularly those younger than 5-10 years or so, is harsher than that faced by older plants[10]. This difference is captured parametrically by ψ. Under Condition 2, plants that update will tend to have relatively high idiosyncratic shocks. Due to ψ, and because unproductive plants quit, these will tend to be relatively old plants or plants that have not recently updated.

The shocks z were taken over a grid of 30 points. Given a particular grid, multiplying it by any factor affects only the size and not the relative composition of the economy. I choose values evenly spaced between zero and five.

[8] The condition on entry is simply that $p\zeta'(m) = w$.

[9] See Hopenhayn and Rogerson (1993).

[10] See Bahk and Gort (1993), Dunne, Roberts and Samuelson (1989) and Evans (1987).

4.1 Functional forms

I must pick forms for the primitives of the model – namely, f the idiosyncratic shock process, ψ the distribution of shocks across entrants, ζ the managerial production function and λ the utility of leisure.

- $f(.|.)$ is specified as an approximation to a first order autoregressive stochastic process over the grid of z values with normal disturbances: $\ln z_{t+1} = \ln z_t + \varepsilon_{t+1}$, where $\varepsilon_t \tilde{} N(0, \sigma^2)$. This form of f satisfies a stochastic dominance condition that yields monotonicity in the exit rule with respect to z.

- $\psi(.)$, the distribution over initial idiosyncratic shocks, is summarized by two parameters that yield a piecewise linear distribution over the lower portion of the domain. ψ is uniform from the lowest shock value until a certain point ψ_1, after which it declines linearly until it reaches zero at another point ψ_2.

- $\zeta(.)$ is assumed to take the simple form[11] $\zeta(m) = m^{\bar{\zeta}}$.

- I set $L(l_t) = -\Lambda l_t$. This assumption is equivalent to the following structure.[12] There is an institutionally determined work week of length 1, so that all agents are either working time 1 or not working at all. Perfect unemployment insurance is available, and which agents get to work is determined by a lottery. This is equivalent to picking a general function L and setting $\Lambda = L(\omega) - L(\omega - 1)$, and conveniently identifies total labor input with total employment.

4.2 Parameter values

Veracierto (2001) performs a carefull growth accounting analysis, reporting that post-war economic growth per head in the US was about 1.56%. I must divide this into γ_E and γ_D. Greenwood et al (1996) and Cummins and Violante (2002) both find via different methods that 60% of economic growth can be attributed to increases in capital-embodied technical change. Hence I set $\gamma_E = (1.0156)^{0.6}$ and $\gamma_D = (1.0156)^{0.4}$.

I choose $J = 3$, $\Phi = \left\{0, \widehat{\phi}, \infty\right\}$, so that establishments that are struck with the highest shock will exit regardless of whatever policies are present. That $\phi_2 = \widehat{\phi} < \infty$ implies that some shocks are bad enough that some plants cannot weather them, whereas others can.

ν is set so that annual population growth is 1.2%. The discount factor is given by $\beta = \frac{\gamma}{1+i}$, set to be consistent with a 5.5% interest rate.[13] The labor income share θ is set to 64%, also an intermediate value among available measurements.

The disutility of labor Λ is chosen so that employment is 80%, which is approximately the portion of the US working age population employed. I set $\bar{\zeta} = 0.2$, which leaves 6% of employment in the managerial form. This is approximately the proportion of employment in Business Services in the US National Income and Product Accounts. Results are insensitive to the choice of $\bar{\zeta}$.

[11] For a decision theoretic basis to this form, see Veracierto (2001).

[12] See Hansen (1986) and Rogerson (1988).

[13] Rates ranging from 4% to 7% are routinely used in the real business cycle literature. I pick 5.5% as an intermediate value.

The functional form for f is $\ln z_{t+1} = \ln z_t + \varepsilon_{t+1}$, where $\varepsilon_t \tilde{} N(0, \sigma^2)$.

λ_3 will determine the extent of closure that impacts all plants. Evans (1987) finds that hazard rates are decreasing in plant age, finding a lowest quinquennial hazard rate of 8.3% among establishments that are older than 95 years. However, the data set covers 1976 to 1982, during which exit rates were higher than usual. Hence I choose λ_3 so that this number is a little lower, about 6%. The proportion of closure due to shocks that are small enough that at least *some* establishments would be capable of surviving them is thus over 80%.

The remaining parameters are those that determine the dynamics of surviving plants and the determinants of shut-downs. I identify them using data on labor flows and cross-cohort size differences, using an algorithm related to simulated annealing to match certain statistics of the size-age distribution of plants.[14] These seven parameters are $\widehat{\phi}, \lambda_2, \psi_1, \psi_2, \sigma$ and κ, and the six statistics I match are:

1. The 5-year plant hazard rate
2. The 5-year hazard rate of plants aged 6 years or less
3. The proportion of employment that undergoes job creation in each year
4. The proportion of job creation due to birth
5. The proportion of job destruction due to exit
6. The average age of equipment

The rationale for matching these particular statistics is broadly as follows. $\hat{\phi}$ and λ_2 should be closely related to the extent of shutdowns and to the magnitude of job turnover that they account for. The size of the young and the amount of job turnover they generate are connected the initial distribution of shocks, and hence to ψ_1 and ψ_2. σ affects the amount of overall job turnover – as of course does κ. Finally, κ also determines incentives to update, and hence should be related to the average age of capital.

Parameter	Value	Parameter	Value
γ_E	1.0093	ψ_1	0.7
γ_D	1.0062	ψ_2	1.3
γ_n	1.012	σ	0.075
θ	0.64	λ_2	0.102
β	0.965	λ_3	0.013
$\overline{\zeta}$	0.2	$\widehat{\phi}$	2
κ	5.02	Λ	0.85

Table 7 – Parameter values

Table (1) lists the resulting parameter values, and Table (2) displays several statistics that characterize the model economy. The matches are quite tight. In particular, even though most

[14] On simulated annealing, see Bertesmas and Tsitsilkis (1993). Data are drawn from Davis and Haltiwanger (1992), Dunne et al (1989), Evans (1987a) and the US National Income and Product Accounts.

closures can be attributed to endogenous factors (i.e. to $\widehat{\phi}$), the difference in exit rates between age groups is small, as in the data. I regard this as a success of the model in yielding realistic plant level dynamics. That $\kappa > 1$ is consistent with the notion that, in terms of opportunity cost, young establishments may have an advantage over old ones when it comes to the adoption of new technologies – see Faria (2003). I also report the proportion of young plants that are "small" in that they are less than 33% of the average size: that match is not too far off the data either.

Statistic	US Data	Model Economy
Exit	36%	36%
Exit, 0-6	40%	41%
Plants, 0-6, that are "small"	74%	80%
Job creation	10%	10%
Job creation from Birth	16%	17%
Job destruction from exit	23%	25%
Average age	7.2	7.8%

Table 8 – Matched statistics

Figure (1) displays the decision rules for the benchmark economy. Establishments are born at some point on the y axis, depending on their initial draw from c. As they age, they move towards the right deterministically, also moving up or down depending on the shock realizations. If at any time while in the area labelled "conditional exit" they receive a draw from Φ of $\widehat{\phi}$, then they optimally choose to exit. In any other region, they do not exit and simply pay the continuation fee. If they receive a draw from Φ of ∞, then they exit unconditionally. Finally, if they at any point enter the region labelled "Update" then they return to the y axis, with a new shock value drawn from $f(\cdot|z_t)$.

That continuation shocks are not persistent embodies the notion that there is such a thing as a temporary downturn that is unrelated to the long term viability of the establishment. On the other hand, setting $\phi_J = \infty$ captures the notion that organizations may fail for reasons that are related to their long term viability. Subsidies only apply to establishments that maintain their long term viability: in other words, only plants suffering from a $\widehat{\phi}$ shock may benefit.

5 Employment Protection

5.1 Diffusion and Employment Protection

In this section I examine the effects of imposing a firing tax in this economy. I do so by imposing a firing tax of τ years' wages, that is redistributed lump-sum to the agents. In what follows I report results for $\tau = 1$.

Like related models, firing costs decrease employment and steady state consumption, leading to a loss of welfare. Job creation is suppressed and, interestingly, entry and exit become more

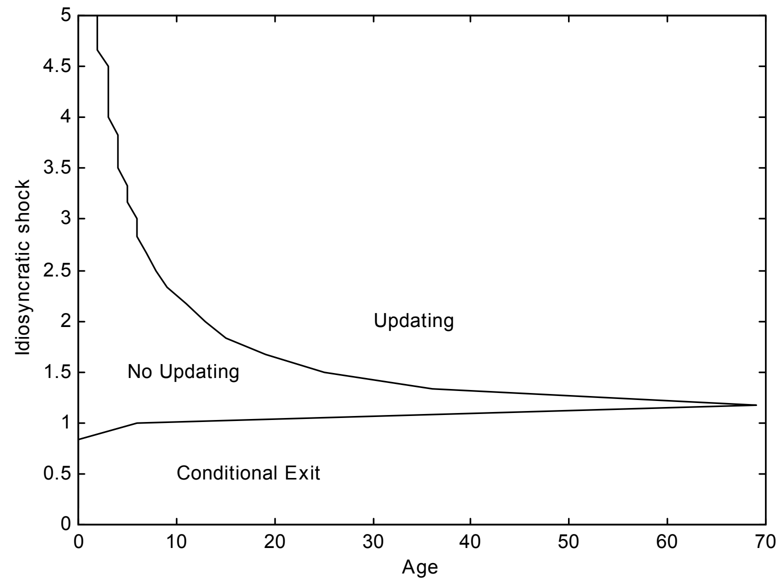

Figure 1: Decision rules, benchmark economy.

important factors of job turnover. Plants are born and

Statistic	$\tau = 0$	$\tau = 1$
Consumption	100	98
Employment	80%	78%
Welfare	100	99
Exit	36%	34%
Exit, 0-6	41%	41%
Plants, 0-6, that are "small"	80%	80%
Job creation	10%	4.5%
Job creation from Birth	17%	26%
Job destruction from exit	25%	48%
Average age	7.8%	8.0%

Table 9 – Employment Protection

Firing costs also slow the equilibrium rate of technical diffusion. This is seen in that the average age of capital increases. Indeed, the entire vintage distribution is flattened. If we interpret IT as being associated with the more recent vintages of capital, this suggests that IT will be less prevalent in countries where firing costs are high.

5.2 IT and Employment Protection

Now I examine the effect of an increase in γ_E. Greenwood et al (1997), Cummins and Violante (2001) and Samaniego (2004b) find that, since the mid 1970s, there has been both an acceleration of embodied technical change and a deceleration of disembodied technical change. Samaniego

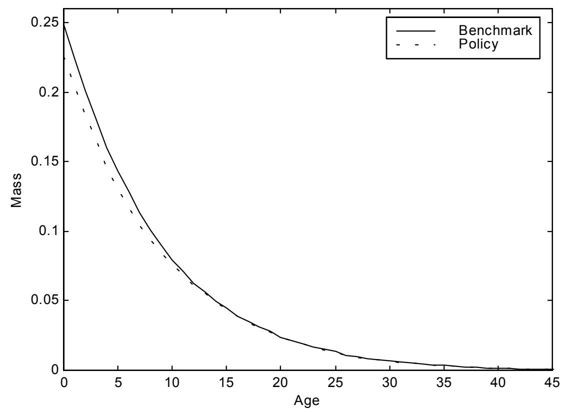

Figure 2: Vintage distribution, 60% embodied growth.

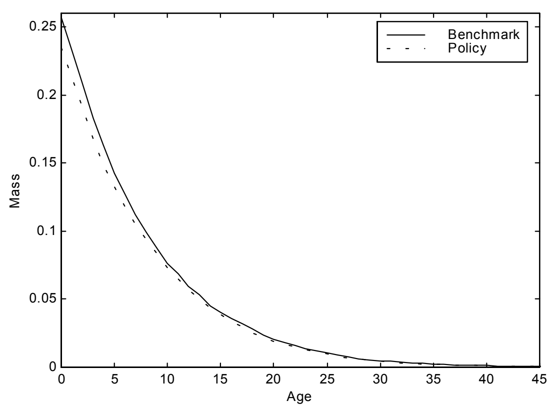

Figure 3: Vintage distribution, 100% embodied growth.

(2004b) finds that most productivity growth has been embodied since then, using data for both equipment and structures. Using only data for equipment, Greenwood et al (1997) find that it has accounted for *more* than 100% of productivity growth, with disembodied technical change *falling* over the period. Using a more detailed procedure, Cummins and Violante (2001) find that it has been entirely embodied.

I take a middle course and assume that the entirety of growth is embodied. This implies that $\gamma_E = 1.0156, \gamma_D = 1$. I compare across steady states in order to focus on the long run effects of the change.

I find, first of all, that the long run effect of this change is to increase employment. This is regardless of whether or not firing costs are present. However, this employment effect is dampened by dismissal costs. As a result, the employment gap between economies widens.

Observe that the average age of capital is *more* suppressed in the economy with firing taxes than before. Moreover, the employment effect of firing costs is exacerbated.

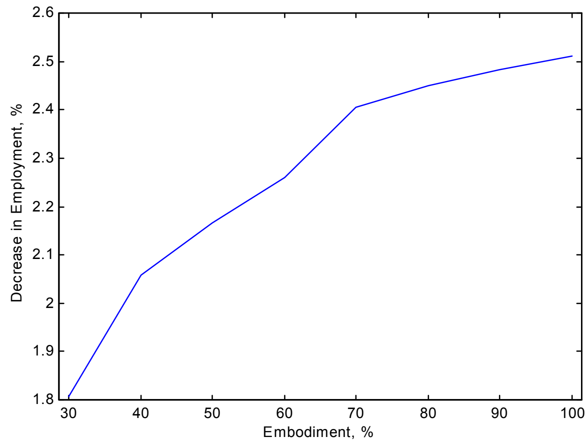

Figure 4: Employment, embodiment and dismissal costs. The independent variable is the proportion of growth that is embodied.

5.3 Trend or Turbulence?

Is this the result of increasing variability in the optimal scale of operations, or of the fact that the optimal scale tends to decrease more sharply over time?

To answer this question, I recalibrate the model economy for a variety of values of γ_E. This allows a comparison across economies that differ in terms of γ_E, but with all the matched statistics approximately the same, including the level of overall turnover. The question is, what are the long run effects of changing γ_E net of any other changes?[15] This exercise has the additional benefit of demonstrating whether the rate of technical change is, in isolation from other factors, sufficient to change the impact of dismissal costs.

I find that the employment loss from the imposition of dismissal costs is increasing in γ_E – see Figure (4). This suggests that it is predominantly not the "turbulence" effect that leads to a suppression of employment after an increase in γ_E, but rather the "downward trend" in productivity that this imposes.

In a related model, De Michelis (2003) proves that the severity of the employment effects of firing costs is related to the relative likelihood of a downward productivity transition. He interprets this as suggesting that firing costs are more damaging in recessions.

While it may or may not be the case that this is a reasonable characterization of a recession, the likelihood of a downward transition will be related to the rate at which establishments fall behind the productivity frontier – i.e., it should depend on the rate of embodied technical change. This precisely what I find here.

Interestingly, Figure (5) shows that the decrease in the average age of capital decreases in γ_E. A given change in the average age of capital is more costly when γ_E is high, due to accelerated obsolescence. The economy responds optimally by minimizing changes to the age structure of capital.

[15] Thus, $\gamma_E \gamma_D$ remains constant across experiments. See appendix for parameter values and matched statistics.

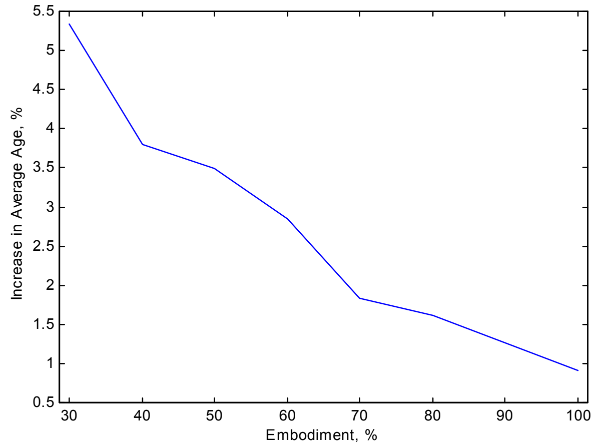

Figure 5: Average age and embodiment.

6 Discussion

The model finds that an increase in the rate of embodied technical change is associated with a widening of employment outcomes across countries, as a result of an interaction with EPL.

A prediction of the model is that newer technologies should be less prevalent in economies in which employment protection is strict. In this section I present some evidence that there is a relationship between IT penetration and employment protection. If one identifies it with "newer technologies", such evidence should be consistent with the model.[16] I take as an assumption that IT is related to an increase in the rate of embodied technical change: extensive aggregate and industry-level evidence is provided in Gordon (1990) and Cummins and Violante (2001).

I use data for 20 OECD countries.[17] As always, there are many problems with cross-country policy regressions including the fact that empirical relationships could be spurious. I address this by considering several IT penetration indices, as well as a number of policies that one might expect to matter for IT.

As a measure of employment protection I use the broad index developed by Nicoletti et al (2000), using 1998 data. This measure is predominantly composed of severance pay and advanced notice requirements. I refer to it henceforth as EMP.

I use a variety of measures of IT drawn from Coppel (2000) and Pilat and Lee (2001). I use two measures of the prevalence of e-commerce: the number of internet hosts and the number of secure servers[18] relative to the population. Secure servers are likely to be the stronger index, as the internet has other non-commercial uses which will be related to the number of hosts, whereas

[16] Bartelsman and Hinloopen (2002) provide similar evidence, although they do not compare the influence of different policies.

[17] These countries (chosen on the basis of data availability) are: Austria (AUT), Australia (AUS), Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the UK and the US.

[18] An internet host is any computer with full two-way access to the network and thus carries an IP address. The density of secure servers is an indicator of the distribution of e-commerce across countries. Every computer that contains websites is a server. See Coppel (2000).

the primary use of secure servers is to transmit private such as credit card numbers. I also use other more direct measures that are listed in Table (1).

Name	**Diffusion Index**
HOST	Internet size: Internet hosts per thousand inhabitants, 1999.
SERV	E-commerce: Secure servers per million inhabitants, 2000.
PCS	PC base: Average number of PCs per capita, 1999.
ITSP	Share of ICT spending in GDP, 1992-1999.
ITEMP	Share of ICT in business sector employment, 1998.

Table 1 – IT penetration measures

Table (2) and Figures (6) and (7) reveal a fairly striking negative relationship between IT penetration and the intensity of employment protection. Except for ITEMP, all such correlations are highly significant.

Name	Correlation	P-value
HOST	-60%	0.4%
SERV	-82%	0.0%
PCS	-59%	0.5%
ITSP	-78%	0.0%
ITEMP	-16%	50%

Table 2 – IT penetration measures and EMP, correlations and significance.

A problem with cross-country policy analysis is that results could be due to other policies that are correlated with the policy of interest. Hence, I perform a number of simple regressions including several additional policy variables.

Nicoletti et al (2000) provide indices of several policy indices. They come under two broad categories: employment protection (EMP) and product market regulation (PRO). The main components of EMP are dismissal costs and advance notice requirements, whereas PRO captures general regulation including general state involvement in operations and in ownership, as well as measures of market openness. I include these two indices as regressors. One might expect PRO to be potentially related to IT in a number of ways, for instance via extra administrative burdens.

I also include data for industrial subsidies (IND) and the costs of entry (ENT). Most industrial support consists of transfers to ailing establishments, so these should constitute a potentially important determinant of the decision to retire ageing plants, which could "crowd out" the new.[19] On the opposite margin, the cost of entry might affect the decision to establish new plants in new industries. ENT is drawn from Djankov et al (2002), and takes account of corruption as well as formal entry costs. Industrial support IND is the reported proportion of GDP spent on industrial subsidies for 1971-1988, drawn from the OECD national accounts and reported in Ford

[19] See Samaniego (2003a).

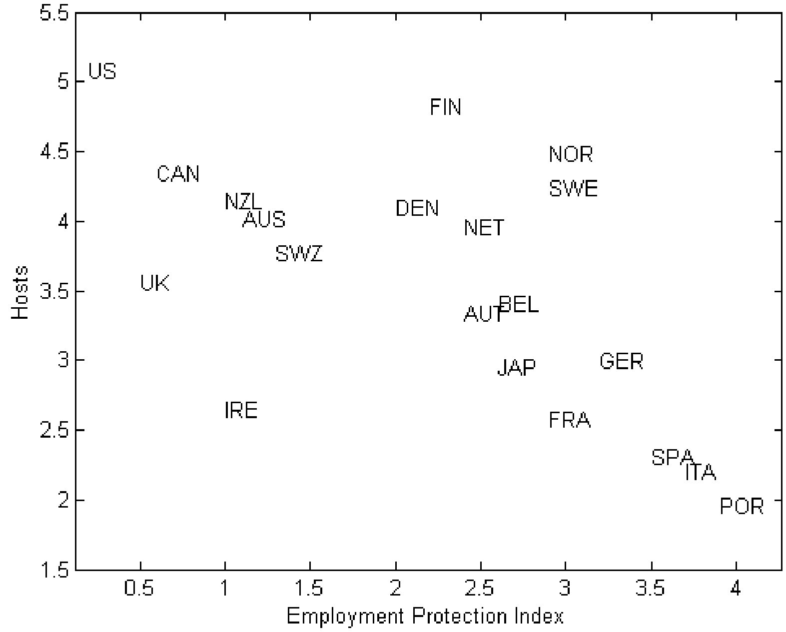

Figure 6: Employment Protection and Internet Hosts per 1000 inhabitants. Correlation: -60%.

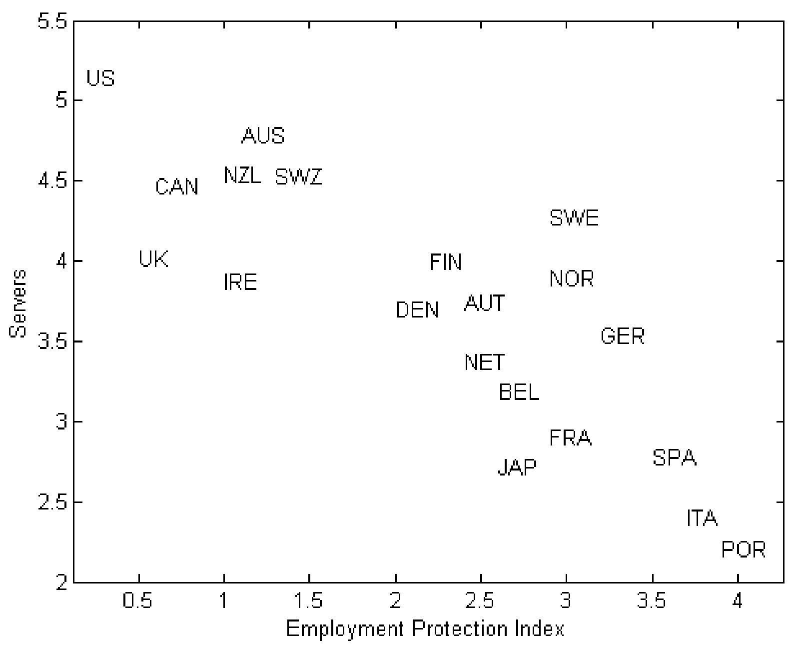

Figure 7: Employment Protection and Secure servers per million inhabitants. Correlation: -82%.

and Suyker (1989).[20]

Name	Policy Index
EMP	Broad employment protection measure
ENT	Entry costs
IND	Industrial Subsidy rates
PUB	Extent of public ownership
PRO	Product market regulation
TRA	Barriers to International Trade and Investment

Table 3 – Policy variables

I include two further variables from the Nicoletti et al (2000) data set: TRA (barriers to trade) and PUB (the extent of public ownership). Pressures from international trade are often cited as an important reason for the closure of plants.[21] The variable TRA should capture the effects of this channel, which may be distinct from those related to PRO. Indeed, this variable turns out to be uncorrelated with PRO.

Ford and Suyker (1989) and Leonard and Van Audenrode (1997) point out that much industrial support is implicit through, for example, government ownership of companies. Hence, national accounts data may miss certain forms of industrial support that might impact resource reallocation. This is why I include PUB. PUB is the only policy variable that is correlated with industrial subsidies, and may potentially be a good indicator of omitted industrial support. Thus, both PUB and IND are included.

While industrial subsidy data is for the period 1970-1988, measurements for the other policies were performed in the 1980s and 1990s. This is unlikely to influence results, however, as regulatory regimes are generally very stable. Nicoletti et al (2000) find that EMP and PRO remain almost unchanged between the 1980s and 1990s.

Variable	ENT	EMP	IND	PUB	PRO	TRA
ENT	-	+56	+25	+37	+45	-24
EMP	+56	-	+65	+66	+80	-26
IND	+25	+65	-	+85	+45	-16
PUB	+37	+66	+85	-	+69	-1
PRO	+45	+80	+45	+69	-	+18
TRA	-24	-26	-19	-1	+18	-

Table 4 - Correlations among policy variables.

[20] Murphy and Pretschker (1996) include a few later years; however their series is shorter, not constructed in the same manner, and not consistent across countries.

Ford and Suyker (1989) do provide data from other sources with a more comprensive view of industrial support. I do not use this data because the panel is very unbalanced, so that the 20 year average for some countries is the average over only one or two data points and may hence reflect transitory conditions rather than the overall regulatory environment.

[21] See Ford and Suyker (1989), OECD (1996).

Variable	HOST	SERV	PCS	ITSP	ITEMP
HOST	-	+82	+90	+69	+43
SERV	+82	-	+84	+81	+31
PCS	+90	+84	-	+76	+39
ITSP	+69	+81	+76	-	+17
ITEMP	+43	+31	+39	+17	-

Table 5 - Correlations among IT variables.

Table (4) shows that many of these policy variables are indeed highly correlated amongst themselves. This suggests that simple correlations between policy variables and outcome variables should be interpreted with caution. Table (6) also shows strong correlations among many of the IT indices, as would be expected from the results of Table (2).

Variable	EMP	ENT	IND	PUB	PRO	TRA	Adj R^2
HOST	-55**	-56***	-38*	76***	-13	0	62
	-62***	-54***	-34**	68***	-	-	66
SERV	-74***	-30*	-23	51**	-22	2	72
	-86***	-27*	-16	38**	-	-	73
PCS	-44	-50**	-31	63**	-24	7	46
	-57**	-49**	-24	53**	-	-	51
ITSP	-47*	-39**	-27	31	-30	9	62
	-64***	-37**	-18	17	-	-	64
ITEMP	-53	-23	-2	92**	-1	-14	34
	-51**	-18	0	84***	-	-	40

Table 6 – IT and policy. Dependent variables are on the left-most column. Variables are normalized by mean and standard deviation. All coefficients are percentages.
An asterisk (*) denotes significance at the 10% level. Two and three asterisks denote significance at the 5% and 1% levels respectively.

Table (6) displays the results of regressions. I ran a regression with the full set of policy variables, subsequently removing PRO and TRA as they seemed to matter little[22] – which is perhaps surprising. The strongest relationships are clearly those with EMP, ENT and PUB. PUB may be capturing state support for the underlying infrastructure. Barriers to entry ENT are negatively related to IT penetration, which is not surprising since many information technology industries are new. What is surprising is the robust negative relationship between IT penetration and employment protection. Coefficients are standardized, which implies that one standard deviation of difference in employment protection is related to, for example, a recrease in the number of secure servers of 3/4 of a standard deviation.

[22]Since the correlation between EMP and PRO, I repeated several regressions removing EMP instead of PRO. Coefficients on PRO were generally not significant.

There is also the risk of colinearity between IND and PUB. Running regressions without IND generally left a significant coefficient on PUB, whereas the reverse often implied that IND was not significant.

I conclude that there is evidence of a negative relationship between IT and employment protection, and that it is robust to the inclusion of other forms of regulation as alternatives. In fact, the relationship is so strong that it suggests that additional effects may be at work. For example, if capital is internationally mobile, the effects outlined in the model economy may result in industries relocating across borders so that countries with in which EPL is weak will have a comparative advantage in industries in which capital-embodied technical change is rapid.

6.1 Summary

The paper finds that an acceleration of the rate of embodied technical change can lead to a decrease in employment at countries in which EPL is strong. Although such an acceleration is associated with an increase in turbulence, it is not this effect that leads to this employment effect: rather, it is because the optimal scale of operations decreases faster, so jobs are shorter-lived in expectation. Moreover, I find that EPL can slow the diffusion of new technologies. An interesting extension would be to study the transition between a regime in which embodied technical change is slow to one that is faster. During transition, many establishments may find themselves unsustainably large, – having hired previously with the expectation of relatively long-lived jobs. As a result, they might be more reluctant to fire in an environment in which EPL is strict, leading to medium-term labor market dynamics that could involve a further divergence between countries with regulatory regimes.

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A Propositions and Proofs

Proofs all employ standard recursive methods. Let v be a uniformly continuous function and let B be the Bellman operator. W is the fixed point $v : Bv = v$, if any, of

$$C(j,\tau,z_t;v) = \max\left\{0, U(z_t;v) - \phi_j p_t, E_{z_{t+1}} v(\tau+1, z_{t+1}) - \phi_j p_t\right\} \quad (4)$$

$$U(z_t;v) = \max_{\tau' \leq \tau}\left\{E_{z_{t+1}} v(\tau', z_{t+1}) - \kappa\gamma_E^{-\tau'} p_t\right\} \quad (5)$$

$$Bv(\tau, z_t) = \max_n \left\{\gamma_E^{-\tau} z_t n_t^\theta - wn + \frac{\gamma}{1+i}\sum_j \lambda_j C(j,\tau,z_t;v)\right\} \quad (6)$$

Let Υ be the optimal updating rule and X be the plants' optimal exit rule. Then,

$$\Upsilon(\tau, z_t; v) = \arg\max_{y\in[0,1]} yU(z_t;v) + (1-y) E_{z_{t+1}} v(\tau+1, z_t)$$

$$X(j,\tau,z;v) = \arg\max_{x\in[0,1]} x \cdot \left[\Upsilon(\tau,z_t) U(z_t;v) + (1-\Upsilon(\tau,z_t)) E_{z_{t+1}} v(\tau+1, z_{t+1}) - \phi_j p_t\right]$$

Assume that w and p are positive and finite.

Lemma 1 W exists, is unique, is strictly decreasing and strictly convex in plant age τ.

Proof It is straightforward to show that the recursive system described above satisfies Blackwell's sufficient conditions for being the unique fixed point of the Bellman operator defined over the appropriate function. By the contraction mapping theorem, for any $\underline{\Omega}$ that is compact under the uniform norm, if $\omega \in \underline{\Omega}$ and $Bv \in \underline{\Omega}$ then $W \in \underline{\Omega}$. This applies to the claim that W is weakly decreasing, as well as to the claim of convexity.[23] In addition, considering an *open* set $\Omega \subset \underline{\Omega}$, if $Bv \in \Omega$ for any $v \in \underline{\Omega}/\Omega$ (which is closed), then $W \in \Omega$ (as the limit cannot be in $\underline{\Omega}/\Omega$) This applies to the claims of strictness.

Lemma 2 Assume that Condition 2 holds. W is strictly increasing in z.

Proof Assume that v is increasing in z. Then, $E_{z_{t+1}} v(\cdot, z_t)$ – the value of *not* updating – is increasing in z also – as is U – because $f(\cdot|z)$ is increasing in z. Consequently, Bv is also, as the instantaneous payoff is strictly increasing in z. Arguments identical to those in Lemma 1 yield strictness.

Proposition 1 If a plant with individual state (τ, z) updates, then one with (τ', z), $\tau' > \tau$ does also.

Proof Observe that U does not depend on τ. Hence, since the alternative to updating is decreasing in τ, the updating rule must be increasing.

Proposition 2 All updating is to the frontier.

[23] Consider v decreasing in τ. Then, U and C are either constant in or decreasing in τ, as is the rest of Bv. The same applies to the claim of convexity, since the supremum of any set of convex functions must itself be convex.

Proof Rewrite the Bellman equation with a change of variables $x \equiv \gamma_E^{-\tau}$.

$$\begin{aligned}
\tilde{C}(j, x, z_t; v) &= \max\left\{0, U(z_t; v) - \phi_j p_t, E_{z_{t+1}} v\left(x\gamma_E^{-1}, z_{t+1}\right) - \phi_j p_t\right\} \\
\tilde{U}(z_t; v) &= \max_{0 \leq x' \leq 1}\left\{E_{z_{t+1}} v(x', z_{t+1}) - \kappa x' p_t\right\} \\
Bv(x, z_t) &= (x z_t)^{\frac{1}{1-\theta}} w^{\frac{-\theta}{1-\theta}}\left[\theta^{\frac{\theta}{1-\theta}} - \theta^{\frac{1}{1-\theta}}\right] + \frac{\gamma}{1+i}\sum_j C(j, x, z_t; v)
\end{aligned}$$

This defines a contraction as before. Let $\tilde{W}$ be the fixed point. It is easily shown that the fixed point is increasing and convex in x, since $\frac{1}{1-\theta} > 1$. Thus, $\int \tilde{W}(x', \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z} - \kappa x'$ must be strictly convex in x', as $\tilde{W}(x', \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z}$ is the weighted sum of strictly convex functions. Consequently,

$$\max_{0 \leq x' \leq 1} \int W(x', \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z} - \kappa x'$$

only allows boundary solutions 0 and 1. However,

$$\begin{aligned}
\lim_{x' \to 0} \int W(x', \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z} - \kappa x' &= \int W(0, \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z} \\
&< \int W(x\gamma^{-1}, \widetilde{z}) df(\widetilde{z}|z) d\widetilde{z} \; \forall x > 0
\end{aligned}$$

so that inertia is always more profitable than reversion to $x = 0$ (equivalent to $\tau = \infty$) and the result follows. Observe that this last argument also proves that plants will never "downgrade" their capital.

Proposition 3 If a plant of type (τ, z) prefers to update, one of type (τ, z') does so too for $z' > z$.

Proof Let $\Delta(\tau, z_t) = U(z_t) - E_{z+1} W(\tau, z_{t+1})$. Then

$$\begin{aligned}
\Delta(z_t) &= EW(0, z_t) - EW(\tau, z_t) - \kappa p \\
&= EF(0, z_t) - EF(\tau, z_t) + \frac{\gamma}{1+i}\left[C(j, 0, z_t) - C(j, \tau, z)\right] - \kappa p
\end{aligned}$$

$$\begin{aligned}
\Delta(z_t) = \; & E_{z_{t+1}}\left\{\max_n \gamma_E z_{t+1} n^\theta - \max_n \gamma_E^{-\tau} z_{t+1} n^\theta\right\} \\
& + \frac{\gamma}{1+i}\sum_j E_{z_{t+2}}\left\{\max\left\{\begin{array}{c} 0, \Delta(z_{t+1}) - \phi_j p_t + \\ E_{z_{t+1}} W(1, z_{t+1}), E_{z_{t+1}} W(1, z_{t+1}) - \phi_j p_t \end{array}\right\}\right. \\
& \left. - \max\left\{\begin{array}{c} 0, \Delta(z_t) - \phi_j p_t + E_{z_{t+1}} W(\tau+1, z_{t+1}), \\ E_{z_{t+1}} W(\tau+1, z_{t+1}) - \phi_j p_t \end{array}\right\}\right\}
\end{aligned}$$

Taking W as given, this expression can be rewritten for Δ in the form of equation (6) to define a contraction that satisfies Blackwell's conditions and which can be shown to be increasing in z because both W and the static labor maximization problem are.

Proposition 4 The exit rules are increasing in τ, and decreasing in z.

Proof This result stems directly from the monotonicity results in Lemmata 1 and 2.

B Computing μ

In a steady state, it must be that the entry rate, exit rules and updating rules are the same in every period. The transition function G must be consistent with X and Υ in that it must satisfy:

$$\begin{aligned}\mu_{t+1}(\Theta \times Z) &= \frac{1}{\nu}\sum_{\tau \geq 0}\sum_{j}\int_{Z}\int_{\Re}(1 - X(k,\tau,z_t))\left(1 - \Upsilon(\tau,z)\right) \\ &\quad \times \mu_t(\tau,z_t)f(\widetilde{z}|z_t)dz_t d\widetilde{z} \\ +E_t 1(0 &\in \Theta)\psi(Z) + \frac{1(0 \in \Theta)}{\nu}\sum_{k}\int_{Z}\int_{\Re}(1 - X(\phi_k,\tau,z_t))\,\Upsilon(\tau,z)\,\mu_t(\tau,z_t)f(\widetilde{z}|z_t)\end{aligned}$$

where $\Theta \times Z$ is any subset of the idiosyncratic state space and $1(.)$ is a function that equals one if the argument is true and zero if not. In a stationary equilibrium, X, Υ and E will be constant, and μ will be the fixed point of this functional.

To compute μ I adopt an iterative procedure. Define a measure μ_1^1 such that

$$\mu_1^1(\Theta \times Z) = E1(0 \in \Theta)\psi^1(Z)$$

where $\psi^1 = \psi$. This is the measure if all plants die after one period. Let μ_2^1 be the measure computed according to X and Υ on the assumption that all updating results in death and that all plants die after 2 periods. Similarly, define μ_i^1. Define $\mu^1 = \lim_{i\to\infty}\mu_i^1$. If there is no updating, this is the steady state measure consistent with X and Υ. Otherwise, define ψ^{j+1} to be the mass of establishments of age zero in μ^j, so that

$$\begin{aligned}\psi^{j+1}(Z) &= \psi^j(Z) + \frac{1}{E}\sum_{k}\int_{Z}\int\left[\sum_{\tau\in\Theta}\Upsilon(\tau,z)\left(1 - X(\phi_k,\tau,z_t)\right)\mu^j(\tau,z_t)f(\widetilde{z}|z_t)\right]dz_t d\widetilde{z} \\ \mu_1^j &: \mu_1^j(\Theta \times Z) = E1(0 \in \Theta)\psi^j(Z)\end{aligned}$$

ψ^{j+1} – which is the distribution of establishments in μ^1 who are using the most recent technology either through birth or updating – can be used to repeat the above procedure and generate a sequence of measures $\{\mu_i^j\}_{i=0}^{\infty}$ for any j. Define $\mu_j = \lim_{i\to\infty}\mu_i^j$. The steady state measure will be $\mu \equiv \lim_{j\to\infty}\mu^j$. A sufficient condition for the existence and finitude of μ is that $\phi_J = \infty$ and $\lambda_J > 0$ (in words, that in any given period there is a positive probability that establishments will close regardless of type).

The advantage of using a discretized state space, as I do, is that this algorithm is easy to implement and fast to run (on a Pentium III it takes a few seconds). μ can be approximated to any desired degree of precision by computing μ_i^j for sufficiently large values of i and j. In practice I use $i = j = T$. Usefully, employing this algorithm for $i = j = T' < T$ is equivalent to tracking the activities of all establishments that are younger than T', making it simple to keep track of individual cohorts in spite of the fact that updating means that τ does not necessarily equal establishment age.

C Varying γ_E

In this section I discuss the parameters and summary statistics for a variety of values of γ_E. The values of γ_E that I examine cover between 30% and 100% of economic growth. I do not examine values below 30% because their match of the average age of capital was not good.

Embodiment	30%	40%	50%	60%	70%	80%	90%	100%
κ	2.72	2.75	2.80	2.57	2.33	2.17	2.06	1.95
ψ_1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
ψ_2	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3
σ	0.078	0.077	0.076	0.075	0.074	0.075	0.073	0.073
λ_2	0.086	0.086	0.086	0.086	0.086	0.086	0.086	0.086
λ_3	0.013	0.013	0.014	0.013	0.013	0.013	0.013	0.014
$\widehat{\phi}$	4.70	4.32	3.99	3.55	3.38	3.14	3.09	3.07
Λ	0.84	0.84	0.85	0.85	0.85	0.86	0.86	0.087

Table A1 – Parameters. The percentage of embodiment represents the proportion of growth that is attributed to capital-embodied technical change.

Table ($A1$) displays the parameters that varied across economies that also differred in terms of γ_E. It can be observed that Λ is increasing in γ_E, whereas σ, $\widehat{\phi}$ and κ are decreasing. Other parameters do not vary significantly across economies.

Embodiment	30%	40%	50%	60%	70%	80%	90%	100%
Exit	36%	36%	36%	36%	36%	35%	35%	36
Exit, 0-6	40%	40%	41%	41%	41%	40%	41%	41%
Plants, 0-6, that are "small"	77%	80%	75%	80%	82%	84%	81%	81%
Job creation	10%	10%	10%	10%	10%	10%	10%	10%
Job creation from Birth	16%	16%	16%	17%	17%	16%	17%	18%
Job destruction from exit	22%	25%	25%	25%	24%	22%	23%	23%
Average age	8.3%	8.1%	8.0%	7.8%	7.6%	7.5%	7.4%	7.3%

Table A2 – Parameters. The percentage of embodiment represents the proportion of growth that is attributed to capital-embodied technical change.

Table ($A2$) sets out the summary statistics used in calibration for each economy. Two observations should be made. First, the rate of job turnover is increasing in γ_E. Second, the average age is decreasing in γ_E. In isolation each of these factors is understandable. *** However, the whole point is to get around this. Hence the second exercise. Report results for that also.