Entry, Exit and the Rate of Technical Change

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Abstract

The paper asks whether cross-industry variation in rates of entry and exit can be attributed to different industry-specific rates of technical change. I develop a general equilibrium model of the firm lifecycle in which technical progress is either disembodied, or else embodied in the capital goods used by firms in each industry. In the model, the rate of entry and exit may depend on the rate of embodied technical change (ETC). Empirical evidence from 18 countries supports a positive relationship between the rate of ETC, entry and exit.

JEL Codes: H25, L16, L63, O33, O38.

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1 Introduction

It is known that entry and exit rates differ significantly and persistently across industries. For example, using quinquennial data over the period 1963-1982, Dunne et al (1988) find that rates of entry vary across US manufacturing industries from 21% in Tobacco to 60% in Instruments. Entry and exit rates tend to be highly correlated in cross section,[1] suggesting that there exist industry-specific factors that lead them

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[1] The correlation between entry and exit rates reported in Dunne et al (1988) for US manufacturing industries is 74%, and significant at the 1% level. Brandt (2004) finds a similar correlation in European data that includes service industries also.

to differ systematically in terms of overall firm turnover. At the same time, little is known about the determinants of these differences, and any insights into these factors could shed light on the determinants of firm turnover overall, and of the firm lifecycle in general. What factors lead some industries to experience higher firm turnover than others?

It is well known that industries display long-term differences in their rates of technical change. The surveys of Geroski (1995) and Bartelsman and Doms (2000) observe that episodes of entry and exit appear related to technological progress, although the focus has been on the contribution of entry and exit to industry productivity change. This suggests looking to differences in rates of technological progress as potential determinants of industry turnover. One can distinguish between two broad notions of technological progress, however: embodied and disembodied. *Embodied technological change (ETC)* requires firms to adopt new technologies through the use of improved capital goods, the reorganization of the productive process, etc, and thus requires the costly replacement of a firm asset. By contrast, disembodied technological change (DTC) can be adopted at negligible cost.

This paper asks whether an important role in the process of entry and exit is played by the rate of technical change in the capital goods that the industry uses. This rate is widely termed the rate of *capital-embodied technical change*, or capital-ETC. To this end, I develop a general equilibrium model of the firm lifecycle in which firms choose the vintage of the capital that they use in production. I refer to this vintage as a *technology*. In the model, the firm is a technology-manager pair: the manager accumulates expertise with a given technology over time, and at any point in time may choose to upgrade to a newer technology – at the expense of part of her expertise. She may also choose to close the firm at any point in time, in which case she may choose to open a new firm in any industry.

In the model economy, I prove that only long-term differences in ETC can affect the rate of entry and exit, not DTC. Moreover, abstracting from firm dynamics other than the exit decision, I prove that the rate of firm turnover is *positively related to the industry rate of ETC* in the model economy. As the firm falls behind the frontier technology for its industry, its profits decline, and this decline is more rapid when the rate of ETC is high. Both ETC and DTC are ultimately absorbed by product prices in each industry. However, since it is costly to return to the frontier for ETC, firms may optimally choose to lag behind the frontier for a time and this allows ETC to affect firm dynamics, the timing of exit, and hence the overall rate of turnover.

I also report evidence that the rate of ETC accounts for a significant portion of cross-industry differences in entry and exit rates. Using comprehensive data on 41 industries across 18 countries, I find strong correlations between ETC as measured in the United States and rates of entry and exit. In addition, I exploit cross-country differences in institutionally-imposed entry costs to assess whether these costs disproportionally affect turnover in industries in which the rate of ETC is high. Most previous empirical work on entry and exit has focused on the manufacturing sector, and an additional contribution of the paper is to assess whether these cross-industry comparisons are robust to allowing for industries in other sectors also.[2]

Interpreted broadly, the model suggests that technical progress only affects entry and exit dynamics to the extent that benefiting from progress is costly so that firms may optimally choose to spend (or are forced to spend) time falling behind the technological frontier. The model implements this for the case of technical change embodied in capital. Clearly there may be other forms of technical change that are not embodied in capital per se, but in other aspects of the firm. However, I chose to focus on ETC because technical progress affecting capital goods is something for which precise measures can be constructed. In addition, Geroski (1989), Audretsch (1991) and others suggest that technical change may itself be a response to entry and exit, so that industries that experience high rates of turnover for other reasons may experience a lot of innovation. In this case, measures of technical change may be endogenous to the process of entry end exit. Even if this is true, however, it is unlikely to be the case for capital-ETC. ETC data are based on prices of capital goods, which are used in many industries and are thus unlikely to respond to conditions in any particular demanding industry.

Section 2 introduces the model, while Section 3 characterizes the equilibrium. Section 4 studies the relationship between ETC and turnover in the model. Section 5 surveys the empirical relationship between entry, exit, and the rate of ETC. Section 6 concludes with a discussion of the results, and suggestions for further work.

2 Economic Environment

2.1 Overview

There are $I \subset \mathbb{R}$ industries. There is a continuum of firms that live in discrete time. The length of time between periods is Δ. A firm is a technology, implemented by a manager by hiring and combining inputs, with a degree of success that is stochastic yet persistent.

[2] A notable exception is Brandt (2004), who argues that rates of entry and exit do not vary much across countries except for industries related to information technology. This is consistent with the results of the present paper in that, as we shall see, there are among the industries in which the rate of ETC is highest.

In the model, a technology represents a *level* of investment-specific technical change. There is a capital sector that converts the numeraire good into capital goods, and the efficiency of capital production differs by industry and varies across technologies. To change the vintage of their technology, firms must update it: updating, however, may decrease their expertise, part of which is vintage-specific. Also, at any point, the manager may choose to close the firm if the payoff from her outside options exceed that of continuation. As a result, firms may find it optimal to be temporarily "locked" into a particular technology, investing in capital of a type that is not at the industry frontier, and updating or exitinig depending on the efficiency of implementation.

2.2 Households and investment

There is an aggregate good y_t which is the composite of the output of the I industries:

$$y_t = \prod_{i=1}^{I} \left(\frac{y_{it}}{\omega_i} \right)^{\omega_i}, \omega_i > 0, \sum_{i=1}^{I} \omega_i = 1. \tag{1}$$

It can be used for consumption c_t or for investment j^i_{xt} in capital goods for any industry i. The stock of each type of capital evolves according to

$$k_{x,t+1} = j^i_{xt} x + e^{-\delta \Delta} k_{xt} \tag{2}$$

so that capital depreciates by a factor $\left(1 - e^{-\delta\Delta}\right)$. Thus, at any date, one unit of foregone consumption may be converted into x units of capital of type x in any industry i. x is a measure of investment-specific technical change: the rate at which capital goods used by the firm can be created from the aggregate good. There is a frontier level of x which varies by industry, denoted $\bar{x}^i_t$. It changes over time[3] at exponential rate Δg_i, so that $\bar{x}^i_t = \bar{x}^i_0 e^{-g_i \Delta t}$.

[3] Observe that the structure of capital accumulation in this model resembles that of Greenwood et al (1997), except that there are distinct capital stocks for each sector. There is a subtle difference between the two models, however. In that model there is only one technology for converting consumption into investment, which improves over time. In this model, however, that is not the case: firms have a *choice* over this technology, and the set of available technologies changes over time.

Strictly speaking, this is a model of investment-specific technical change (ISTC) ISTC and ETC are often identified because, to the extent that ISTC occurs through improvements in the quality of capital goods, it is embodied in capital. The use of quality-adjusted capital price data in later sections implies that either terminology is appropriate.

Preferences are from

$$\sum_{0}^{\infty} e^{-r\Delta t} \frac{c_t^{1-\theta} - 1}{1-\theta} dt, \, \theta > 0 \tag{3}$$

The rate of time preference is $\Delta\rho$. Agents die with probability $e^{\lambda\Delta}$ each period: in this case firms that they own close.[4] Thus the agent's discount factor is $e^{-r\Delta}$ where $r = \lambda + \rho$. $1/\theta$ is the intertemporal elasticity of substitution.

Each household is endowed with one unit of labor and k_{xt}^i units of capital of each type. Each type commands a rental rate Δr_{xt}^i and labor a wage Δw_t. Households earn income by renting capital and labor to firms, and by earning profits from the firms. As we will see, firms in industry i are characterized by their type (x_t, z_t), so let the profits of such a firm be $\pi^i(x_t, z_t)$ and let μ^i be the measure over types in each industry.

Their budget constraint is

$$\begin{aligned} & p_t c_t + \sum_{i=1}^{I} \sum_{x=0}^{\bar{x}_t^i} p_t j_{xt}^i \\ \leq \quad & \Delta w_t n_t + \Delta \sum_{i=1}^{I} \sum_{x=0}^{\bar{x}_t^i} r_{xt}^i k_{xt}^i + \sum_{i=1}^{I} \sum_{x=0}^{\bar{x}_t^i} \pi(x_t, z_t) \, d\mu^i(x_t, z_t) \end{aligned} \tag{4}$$

2.3 Production

Goods $i \leq I$ are produced by firms. A firm is characterized by a technology x, and the manager's success in implementing it z_t. z_t and x define the firm, and may not be traded.[5] The firm's production function is

$$\Delta A_{it} z_t k_t^{\alpha_k} n_t^{\alpha_n}, \alpha_k + \alpha_n < 1 \tag{5}$$

where k_t is the quantity of efficiency units of capital that it uses, and n_t is labor. $A_{it} = A_{i0} e^{\Delta \sigma_i t}$ is a measure of disembodied technological progress, which may differ across industries. Thus, g_i is the rate of ETC, and σ_i is the rate of DTC.

Let p_{it} be the competitive price of the output of a firm in industry i. The firm's profits at any date are $\Delta\pi(z_t, x_t)$ where

$$\pi(z_t, x_t) = \max_{k_t, n_t} \left\{ A_{it} p_{it} z_t k_t^{\alpha_k} n_t^{\alpha_n} - r_{xt}^i k_t - w_t n_t \right\} \tag{6}$$

[4] This guarantees that there will always be some entry and exit, although this factor does not affect industries differentially.

[5] Although see Faria (2007) for a related model of mergers and acquisitions.

Thus, although x does not enter into the production function, it affects profits because it changes the rate at which the economy can produce the capital goods that the firm uses, and thus the equilibrium rental rate of capital Δr^i_{xt}. In equilibrium, more efficient technologies are associated with cheaper capital, and this provides an incentive to use the frontier technology (*caeteris paribus*).

However, technology adoption is costly. At any point in time, the firm may choose to update its technology x to the frontier, at the cost of some of their accumulated expertise. In this case, their productivity drops from from z_t to $z_t\zeta_l, \zeta_l < 1$. This reflects the finding that technology adoption coincides with firm reorganization (Sakellaris (2004)), so that some accumulated knowledge may no longer apply to the new technology (Milgrom and Roberts (1990), Jovanovic and Nyarko (1996), Brynjolfsson et al (2002)). This captures the notion that updating and reorganization is a time of potential turmoil at the firm. It is a critical element of the model that there be an opportunity cost to updating.

Finally, firms face a stochastic learning ladder. With probability $\left(1 - e^{-\Delta\eta}\right)$, they may obtain a level of productivity z_{t+1}, drawn from a distribution $f\left(z_{t+1}|z_t\right)$. This is similar to the model of Hopenhayn (1992). $z_t \in [z_l, z_h]$, $z_l \geq 0$, $z_h < \infty$.

2.4 Entry and Exit

Agents in this environment may create and operate firms – one per agent not otherwise engaged. Creating a firm requires a delay of $d\Delta$ periods, after which profits begin to flow. Let $E = 1 - e^{-rd}$. We interpret E as the *cost of entry.* This proportionality captures the finding of Djankov et al (2002) that cross-country variation in entry costs largely takes the form of bureaucratic delays, and with the fact that they measure entry costs as a proportion of GDP. This will be useful later in calibration.

Firms start their lives with a value z_t drawn from a common distribution ψ, and with the frontier technology. At any point in time, the entrepreneur may close the firm, earning a continuation payoff W_t to be discussed in more detail below.

Since agents may either work or create firms, so that in equilibrium entrepreneurialism in any sector experiencing entry must carry the same expected benefit as labor. The return from operating a firm is stochastic: however, we assume complete insurance markets, so there is no income uncertainty for individual agents. Hence, in equilibrium,

$$W_t = \max_i \int V^i\left(\bar{x}^i_t, z_t\right)\psi\left(z_t\right)dz_t\left(1 - E\right) \tag{7}$$

If in equilibrium there is entry into any two sectors i and j, then it must be that

$$\int V^i\left(\bar{x}_t^i, z_t\right)\psi\left(z_t\right)dt = \int V^j\left(\bar{x}_t^j, z_t\right)\psi\left(z_t\right)dz_t \tag{8}$$

In equilibrium, prices p_{it} are such that this free entry condition is satisfied with equality.

Agents may also participate in the labor force. In this case, they earn the flow of income w_t. Expected lifetime income from labor is then

$$W_t = \sum_{\tau=0}^{\infty} e^{-\sum_{s=0}^{\tau}[i(s+t)ds+\lambda]\Delta}\Delta w_{\tau+t}dt, \tag{9}$$

where $i\left(t\right)$ is the interest rate at date t.

3 Equilibrium

Definition 1 *Equilibrium in the model is a list of functions including prices and allocations such that markets clear and agents optimize at each date.*

Definition 2 *A balanced growth path is an equilibrium in which output grows at a constant rate.*

Since we are interested in rates of entry and exit, we need to define this concept for the model.

At any date, let M_t be the set of firms in operation, and let m be any firm. Define for any two dates t, t'

$$\Xi_{t,t'} = \{m : m \in M_t, m \notin M_{t'}\} \tag{10}$$

Thus, for $\Delta > 0$, $\Xi_{t,t+\Delta}$ is the set of firms that exited between time t and $t+\Delta$, whereas $\Xi_{t+\Delta,t}$ is the set of firms that entered between those dates. Let $\mu_t\left(X\right)$ be the measure of any set $X \subseteq M_t$ of firms. Thus, the share of time t firms that do not reach time $t+\Delta$ is $\frac{\mu_t\left(\Xi_{t,t+\Delta}\right)}{\mu_t(M_t)}$, and the share of firms at time $t+\Delta$ that were born since time t is $\frac{\mu_t\left(\Xi_{t+\Delta,t}\right)}{\mu_t(M_t)}$. Then,

Definition 3 *The industry rates of entry and exit are:*

$$Entry_t = \frac{\mu\left(\Xi_{t,t+\Delta}\right)/\mu\left(M_t\right)}{\Delta} \tag{11}$$

$$Exit_t = \frac{\mu\left(\Xi_{t+\Delta,t}\right)/\mu\left(M_t\right)}{\Delta} \tag{12}$$

Proposition 1 *There exists a balanced growth path with positive, constant rates of entry and exit into all sectors.*

The proof of the proposition derives from a series of conditions that are then shown to be consistent with equilibrium. First, for profitability to be proportional across industries requires prices to grow over time at a rate related to the inverses of the rates of embodied and disembodied technical change. This implies that the decision problem of the firms is stationary. This implies that the measure of firms in a given subset of the type space is constant over time which, in combination with the decision variables, enables an expression for $\mu(M_t)$, net of a constant. Finally, for a given wage, product prices and demand are given. It remains to show that there is a wage that clears the labor market. These results are left in the Appendix.

Proposition 2 *At any date, the rental rate of capital decreases with vintage at a rate that is proportional to* g_i.

This result is central to the firm dynamics of the model. Firms using more advanced capital benefit through cheaper capital services than their competitors. On the other hand, the fact that updating to the frontier is costly implies that firms gradually fall away from the frontier, whereas some of their competitors – either because they updated or because they are recent entrants – may use more advanced capital than them. Since the price of the output of industry i is driven by the dynamics of the industry as a whole, this implies that the price of output may decline as the cost of production across the industry declines, whereas any given firm only benefits from decreased costs if they decide to update – which may not be optimal. As a result, g_i introduces a downward trend in the marginal revenue product of the firm over time, net of other aspects of firm dynamics.

This intuition also suggests that rates of entry and exit may not in fact be related to the industry rate of disembodied technological progress, σ_i. Again, the price of the output of industry i is driven by the dynamics of the industry as a whole, implying that the price of output declines at a rate that offsets σ_i. However, since all firms are at the frontier with respect to diesmbodied technical progress, this has no influence on their lifecycle decisions.

Lemma 1 *The firm's updating and exit decisions depend only upon their industry i and the age of their technology* a*, not the date.*

At any date, the value of a firm may be written recursively. Solving for optimal input use, the lemma shows that the firm's behavior is the solution to the problem:

$$\begin{aligned} V^i(a,z) &= e^{\Delta(r+\eta+\lambda)a} \max_T \left\{ \sum_{t=a}^{T} e^{-\Delta(r+\eta+\lambda)t} \left[z_t^{\frac{1}{1-\alpha_n-\alpha_k}} e^{-\left(\frac{\alpha_k g_i}{1-\alpha_n-\alpha_k}\right)a} \right. \right. \\ & \quad \left. + \left(1-e^{-\eta\Delta}\right) E_{z'} V(t,z') \right] \\ &+ \left. e^{-\Delta(r+\eta+\lambda)(T-a)} E_s \max\left[E_{z'} V^i(0,z')(1-E), V^i(0,z)\right] \right\}. \end{aligned} \tag{13}$$

In this problem, notice that prices do not enter, as suggested by the earlier discussion. A crucial reason for this is that the value to an entrepreneur of closing a firm is equal to the opportunity cost of entering other industries and, by optimal sectoral choice, that this in turn is equal to the value of re-entering the same industry. It is not necessary that the entrepreneur be able to re-enter the same industry, but rather that *other* entrepreneurs have a choice over which industry to enter.

Lemma 2 *The optimal updating strategy is an (S,s) policy, censored by the exit rule.*

Define T as the date after which the firm exits or updates or exits. Let Υ equal one if the firm updates. Let X equal one if the firm exits.

Lemma 3 *T, Υ and X are contingent upon z_t and on g_i, but not ω_i, A_{i0}, nor σ_i.*

The firm lives as follows. It is born, and climbs in terms of productivity as it learns, while falling behind the technological frontier. The price of output declines at this rate so that, eventually, learning is offset by price declines due to competition and the firm shrinks until it either updates or – if z is too low – closes. Section 4 studies the form of the relationship between entry, exit and g_i. However, in the meantime, it also interesting to state factors upon which entry and exit rates *do not* depend in the model economy.

Proposition 3 *Entry and exit rules depend on g_i, but do not depend on ω_i (preferences), on A_{i0}, nor on σ_i, the industry rate of disembodied technical change.*

Geroski (1995) notes that there is weak if any evidence of a link between entry, exit and standard profitability measures, noting that profitability must vary across industries much more than the data indicate in order to account for cross-industry variation in entry and exit rates. In this model, expected profitability is in fact constant across industries, because sectoral choice by entrepreneurs implies that any factor that increases profitability in an industry (such as a high level of A_{i0}) will be offset by a corresponding decline in output price, and because the entrepreneur's post-exit opportunity cost includes the possibility of re-entry. Since such a factor affects both the value of all firms in the industry and the value of what the entrepreneur could do if she were to close the firm, it does not affect turnover in equilibrium. On the other hand, ETC only benefits new firms and firms that choose to update. The timing of updating and the decision to exit do depend upon g_i.

At the end, only factors that lead to differences in lifecycle dynamics can affect entry and exit rates. This is not to say that empirically there may not be differences in expected profitability across industries but rather, so long as these differences are relatively stable (as Geroski (1995) suggests that they are), and so long as entry affects the outside option of the entrepreneur, the results should hold.

It is notable that the rate of technological progress in the industry per se does not affect rates of entry and exit. Again, industry trends in and of themselves do not matter: they must be factors of lifecycle dynamics, so that trends affect some but not all firms. Geroski (1989) finds some evidence of a link between productivity change and entry/exit, but this may reflect a correlation between productivity and R&D activity, with the knowledge thus generated being embodied either in new products or new processes. Hence, according to the model, this suggests that some aspect of productivity change is embodied in the firm – perhaps through its stock of R&D. Another interpretation is that, if capital goods measurement is not adjusted for quality, then measured productivity in fact encompasses ETC – see Greenwood et al (1997).

The same applies to demand factors. Demand factors that affect all firms in the industry should not affect firm turnover. If some sectors are subject to frequent changes in tastes then, if firms produced differentiated goods and varieties are costly to shift, then this could potentially be related to entry and exit rates.

4 ETC, entry and exit

4.1 An example

To characterize the impact of ETC on firm turnover, we first abstract for now on all other parameters that determine firm dynamics. In particular, we assume that

Assumption 1 $z_l = z_h$, and $\zeta_l = 0$.

Under Assumption 1, there is no learning and no updating, so the firm's problem becomes one of when – rather than whether – to exit. This focusses the model on the *timing* of exit. It is worth underlining that the purpose of the paper is not to provide a new theory of why exit occurs, as in Jovanovic (1982) or Hopenhayn (1992) for example, but rather about *when* it does so. The effects outlined herein will interact with whatever factors ultimately determine exit.

Proposition 4 *Suppose $\Delta \to 0$. The turnover rate is strictly increasing in g_i.*

Two effects impact whether high g_i involves earlier exit. Firms fall behind the frontier at a rate that depends on g_i, which encourages earlier exit. On the other hand, a high value of g_i also lowers the profits from re-entering, which discourages exit. The proof shows that the first effect dominates the second.[6]

It is worth noting that there exist alternative models have the opposite implication. Some authors view technical progress as a barrier to entry, in which case it should be *negatively* related to ETC – see Geroski (1995). To this author's knowledge, ETC specifically has not been studied.

Returning to the general model where $z_l \leq z_h$, and $\zeta_l \geq 0$, suppose $\Delta \to 0$. Now, firms in industry i solve the problem:

$$\begin{aligned} V^i(0,z) &= \max_T \left\{ \int_0^T e^{-(r+\eta+\lambda)t} \left[z_t^{\frac{1}{1-\alpha_n-\alpha_k}} e^{-\left(\frac{\alpha_k g_i}{1-\alpha_n-\alpha_k}\right)a} + \eta E_{z'} V(t,z') \right] dt \right. \quad (14) \\ &\left. + e^{-(r+\eta+\lambda)T} E_s \max\left[(1-E) \int V(0,z') \psi(z') dz, V^i(0,z) \right] \right\}. \end{aligned}$$

Three new factors may affect the industry rate of entry and exit. First, the possibility of updating makes it difficult to prove the analogue of Proposition 4. Second, the set of firms that exit may depend on g_i. The impact of this effect on turnover is ambiguous, and depends on the following condition. Firms will exit (instead of updating) if $z \leq \zeta_l^{-1} z^*$ where

$$(1-E) \int V(0,z) \psi(z) dz = V(0,z^*) \quad (15)$$

If $z_g^* > 0$, then higher rates of ETC are associated with a larger set of firms exiting. Taking the total derivative of (15)

$$z_g^* = \frac{(1-E) \int V_g(0,z) \psi(z) dz - V_g(0,z^*)}{V_s(0,z^*)} \quad (16)$$

[6]Interestingly, although we do not pursue this in the paper, industries with a high capital share should also experience more entry and exit, something that is consistent with the results of Audretsch (1991).

It is simple to show that $V_s(0, s^*) > 0$, and that V_g is negative and larger in magnutude for larger z. Thus, $z_g^* > 0$ provided that z^* is "large" relative to the shock values drawn by entrants. This dovetails nicely with the fact that low initial shock values are a natural feature of any model that wishes to match the higher exit rates among entrants documented by Dunne et al (1989) among others. On the other hand, z^* is endogenous and itself depends on ψ, so it is hard to derive analytical results regarding this point.

Third, there will also be a threshold z^{**} such that firms drawing $z \leq z^{**}$ exit as soon as their shock value is revealed. z^{**} is given by

$$(1 - E) \int V(0, z) \psi(z) \, ds = V(0, z^{**}) . \tag{17}$$

Again, $z_g^{**} > 0$ provided that z^{**} is "large" relative to the shock values drawn by entrants.

The example above clarifies the dynamics introduced by ETC, by abstracting from other aspects of firm lifecycle dynamics. This is consistent with the focus of the paper on the *timing* of exit, rather than developing a theory of why it is that exit takes place at all. In particular, in the simple model, firms will tend to shrink over their lifecycle until they exit. Exans (1987) does find that exiting firms tend to shrink in the periods before exit, and also find that firms tend to shrink on average. However, surviving firms tend to grow over time, something from which the example abstracts. To assess whether these results are robust to allowing for other dynamics, we may wish to explore a calibrated version of the model. For now, we look to empirical evidence.

5 Empirical evidence

This section investigates the relationship between entry, exit and ETC in the data. We follow two approaches. First, we show that these variables are indeed related in cross section. Second, we use a differences-in-differences approach that exploits cross-country and cross-industry variation in entry and exit.

5.1 Data

Rates of entry, exit and turnover are computed from the Eurostat database which is made available by the European Commission. It includes all firms in the business register for 18 countries, over the period 1997-2004, and is comparable across countries.[7] The measure of entry is the proportion of firms active at a given date in a country that are new, and the measure of exit is the proportion of firms that close.[8] Both of these are averages over the sample period for each country-industry pair. Turnover is the sum of these two measures. For cross-industry comparisons, the industry index of entry, exit or turnover is the industry fixed effect in a regression of country and industry fixed effects on the variable of interest.[9]

The measure of ETC is the inverse growth rate of the quality-adjusted relative price of capital, from Cummins and Violante (2002). I the average over the period 1987-1997, the decade prior to the entry and exit data. I also look at the average over the post-war period 1947-2000. The correlation between the two series is 91%, which underlines the interpretation of the rate of ETC as a long-term industry characteristic.

The industry classification of the BEA input-output tables (which are used to construct the ETC measure) and by Eurostat do not exactly coincide. They can be added up to a crosswalk of 41 industries. Previous research on entry and exit mostly focuses on manufacturing data only, and an advantage of the Eurostat data is that they include data for service sector industries as well as manufacturing industries.

Finally in the cross-country regressions below I use two entry cost measures, from Djankov et al (2002) and from the World Bank (2007), each of which attempt to measure the cost of starting a business as a proportion of GDP per capita. The former is measured in the 1990s, and the latter over the following decade. I call them EC^{DEA} and EC^{WB} respectively. The correlation between them is 68%.

[7] An observation in the dataset is an enterprise, "the smallest combination of legal units that is an organisational unit producing goods or services, which benefits from a certain degree of autonomy in decision-making, especially for the allocation of its current resources. An enterprise carries out one or more activities at one or more locations. An enterprise may be a sole legal unit." (Council Regulation (EEC), No. 696/93, Section III A of 15.03.1993)

[8] Birth rate: number of enterprise births in the reference period (t) divided by the number of enterprises active in t.

Death rate: number of enterprise deaths in the reference period (t) divided by the number of enterprises active in t.

The reported numbers are the country-industry averages over the period 1997-2004.

[9] Thus, for example, if $y_{i,c}$ is entry in industry i in country c, I run the regression:

$$y_{i,c} = \sum_c \alpha_c I_c + \sum_i \alpha_i I_i + \varepsilon_{i,c}$$

where I_c and I_i are country and industry fixed effects. The index of entry for industry i is then the coefficient α_i.

5.2 Results

Table X presents the industry-level data, ranked by turnover. Even without any statistical analysis, there is a noticeable relationship between all three measures of turnover. In addition, there is also a visible positive correlation between these measures and ETC.

Industry	ETC	Exit	Entry	Turnover
Plastics	3.571	7.400	9.374	16.784
Chemicals	5.227	7.669	9.466	17.145
General Machinery	5.065	7.583	9.918	17.512
Other mining	3.430	7.917	9.616	17.544
Utilities	4.817	7.917	9.616	17.544
Electrical machinery	4.617	7.991	9.998	17.999
Food products	4.621	8.986	9.098	18.095
Computers and electronic prod.	5.648	8.516	10.602	19.128
Healthcare	6.381	7.218	11.962	19.191
Transport Equip.	4.346	8.146	11.160	19.317
Primary and fabricated metal prod.	3.706	8.311	11.100	19.421
Nonmetal products	4.745	8.788	10.637	19.436
Petroleum and coal products	4.552	7.881	11.899	19.791
Wood products	4.600	9.170	10.626	19.807
Hotels	3.858	8.315	11.532	19.857
Leather	4.852	10.884	9.495	20.389
Land transport	5.575	9.332	11.431	20.773
Oil and gas extraction	4.732	9.604	11.353	20.968
Waste disposal	5.253	8.630	12.416	21.056
Manuf n.e.c.	4.772	9.428	11.844	21.282
Air transport	9.350	10.371	12.384	22.765
Transport support	5.209	9.379	13.477	22.867
Construction	4.086	9.301	13.724	23.035
Retail Trade	6.031	11.171	11.904	23.085
Textiles	4.697	11.454	11.939	23.403
Restaurants	4.166	10.932	12.965	23.907
Other services	5.324	9.703	14.437	24.151
Water transport	6.198	10.983	13.183	24.176
Wholesale Trade	6.479	11.210	13.057	24.278
Real estate	4.627	9.555	15.197	24.763
Paper, printing, software	5.663	10.184	15.586	25.780
Legal services	7.570	9.239	16.695	25.944
Education	6.511	10.540	15.822	26.373
Technical Services	6.687	10.368	16.018	26.397
Rental services	8.285	11.641	14.889	26.540
Finance (not insurance, trusts)	8.318	12.878	14.317	27.206
Arts, sports, amusement	4.066	10.307	17.203	27.520
Insurance, trusts	6.667	12.727	15.803	28.540
Systems design	8.801	11.731	20.355	32.096
Broadcasting	9.900	11.376	21.209	32.595
Information and data processing	7.916	13.554	20.600	34.165
Median value	5.209	9.428	11.962	22.765

Table 1 – Annual rate of embodied technical change (ETC) and firm turnover. ETC is the quality-adjusted price of capital goods used by each industry in the US, 1987-1997. Entry, exit and turnover are industry fixed effects plus the cross-country average, 1997-2004. Sources – Cummins and Violante (2002), Bureau of Economic Analysis and Eurostat.

These observations are confirmed by the correlations in Table X. Entry and exit rates are highly correlated among themselves, suggesting that it is appropriate to view them as measures of within-industry turnover rather than short term phenomena, as in the model. It is also striking that entry, exit and turnover are very highly correlated with ETC across industries.

	Entry	Exit	ETC
Turnover	0.96*** (0.000)	0.85*** (0.000)	0.70*** (0.000)
Entry	-	0.67*** (0.000)	0.67*** (0.000)
Exit	-	-	0.62*** (0.000)

Table 2 – Correlations between turnover measures and ETC. P-values are in parentheses. In all tables, one, two and three asterisks represent significance at the 10%, 5% and 1% levels respectively.

Another way to assess this relationship is to compute the correlation between ETC and turnover rates for individual countries. These correlations are positive in all cases but one, and they are significant at the 10% level in almost all cases.

Country	Turnover	Entry	Exit
Belgium	0.70***	0.70***	0.47***
Czech Rep.	0.37**	0.27	0.33**
Denmark	0.70***	0.65***	0.75***
Spain	0.39**	0.47***	0.03
Italy	0.70***	0.67***	0.44***
Latvia	0.29*	0.23	0.31**
Lithuania	0.34**	0.30*	0.12
Hungary	0.28*	0.38**	0.05
Netherl.	0.77***	0.73***	0.75***
Portugal	0.40**	0.37**	0.26*
Slovenia	0.25	0.30*	-0.05
Slovakia	0.14	0.16	0.07
Finland	0.58***	0.54***	0.57***
Sweden	0.57***	0.54***	0.44***
UK	0.49***	0.50***	0.35**
Romania	0.59***	0.55***	0.21
Norway	0.59***	0.54***	0.43***
Switzerland	0.75***	0.63***	0.73***

(18)

Table 3 – Cross-industry correlations between ETC (19)
and turnover, by country. (20)

It is worth observing that there are other views of the process of entry and exit that contrast with these findings. For example, Fisman and Sarria-Allende (2004) argue that entry and exit should be least impacted by entry costs in industries that have high technological entry barriers. If rapid technological progress is an entry barrier, one might expect entry and exit rates to be *negatively* correlated with ETC.

It is well known that the costs imposed by the regulation of entry vary across countries. Given that rates of entry vary across industries, one might expect these costs to reduce rates of entry and, most importantly, to do so disproportionately in industries in which the rate of ETC is high. In adition, the model suggests that this should also be the case for rates of *exit*, not just entry.

To test for these effects, I adopt the differences-in-differences approach pioneered by Rajan and Zingales (1998). Let $y_{i,c}$ be a measure of entry, exit or turnover for country c and industry i. Let I_c and I_i denote country and industry fixed effects, respectively. Denote ETC_i to be the measure of ETC for industry i, and let EC_c be a measure of entry costs for country c. Then, we run the following regression:

$$y_{i,c} = \sum_c \alpha_c I_c + \sum_i \alpha_i I_i + \beta_{ETC} ETC_i \times EC_c + \varepsilon_{i,c}. \tag{21}$$

If entry costs reduce firm turnover, we might expect this to be the case primarily in industries in which turnover is common. If these are industries in which the rate of ETC is high, then we would expect the coefficient β on the interaction term between ETC_i and EC_c to be *negative* and significant. By controlling for industry and country fixed effects, this should be the case regardless of other country- or industry-specific factors that might affect rates of turnover.[10]

The presumption is that the rate of ETC (or the ranking) is an industry characteristic that persists across countries. ETC_i is measured by computing the quality-adjusted price series for different types of equipment, and creating an aggregate for each industry based on the weights of each good in the input-output tables. As a result, this assumption amounts to assuming similar input–output tables across countries, and similar rates of technical progress in different types of equipment. Given that the median rate of ETC is about 5% per year, it is unlikely that significant differences in ETC for the same industry across countries could be sustained for long in the absence of draconian import restrictions.

The results of the differences-in-differences regressions are also very strong. All the interaction coefficients are negative, as expected. Moreover, they are significant in 5 of 6 cases. Notably, ETC interacts with entry costs to generate differences in *exit rates* as well as rates of entry, which again is strongly suggestive of the notion that cross-industry differences in turnover are due to long run factors.

[10] Fisman & Sarria-Allende (2004) also use a differences-in-differences approach to examine the effects of entry costs, but with several differences. First, turnover rates are used as independent variables, and the industry turnover rate in the US is interpreted as an index of "inherent" industry entry costs. Thus, their paper does not address the determinants of entry costs In addition, service sector data are not considered in that paper.

	ETC×EC^{DEA}	ETC×EC^{WB}	Obs	R^2
Turnover	-.56** (0.038)	-	719	.63
	-	-.50** (0.050)	719	.63
Entry	-.29* (0.090)	-	724	.62
	-	-.12 (0.506)	724	.62
Exit	-.26* (0.051)	-	721	.48
	-	-.39*** (0.001)	721	.49

Table 4 – Effect on turnover of the interaction between ETC and institutional entry costs. ETC is measured over the period 1987-1997. Country and industry fixed effects are omitted.

I repeated these regressions with ETC measured over the entire postwar period. Results were strikingly similar, supporting the interpretation of the rate of ETC as being a long-term industry characteristic.

	ETC×EC^{DEA}	ETC×EC^{WB}	Obs	R^2
Turnover	-.60**	-	719	.63
	(0.023)			
	-	-.46*	719	.63
		(0.072)		
Entry	-.33*	-	724	.62
	(0.057)			
	-	-.09	724	.62
		(0.607)		
Exit	-.27**	-	721	.48
	(0.034)			
	-	-.37***	721	.49
		(0.001)		

Table 5 – Effect on turnover of the interaction between ETC and institutional entry costs. ETC is measured over the period 1947-2000. Country and industry fixed effects are omitted.

Previous work on entry and exit has generally neglected service sector data. Hence it is of interest to see whether the results are primarily driven by the inclusion of service industries. To see this I repeated the exercise for service industries and non-service industries separately (non-services include manufacturing, extraction and construction). As can be seen below, the results are essentially the same regardless of the broad subset of industries concerned.

	ETC×EC^{DEA}	ETC×EC^{WB}	Obs	R^2
Turnover	-.76** (0.026)	-	328	.56
	-	-.77** (0.047)	328	.56
Entry	-.65** (0.027)	-	332	.57
	-	-.44 (0.117)	332	.57
Exit	-.29 (0.178)	-	329	.58
	-	-.32* (0.083)	329	.58

Table 6 – Effect on turnover of the interaction between ETC and institutional entry costs: non-service industries only. ETC is measured over the period 1987-1997. Country and industry fixed effects are omitted.

	ETC×EC^{DEA}	ETC×EC^{WB}	Obs	R^2
Turnover	-.78** (0.026)	-	391	.56
	-	-.72** (0.029)	391	.56
Entry	-.41* (0.074)	-	392	.58
	-	-.29 (0.201)	392	.58
Exit	-.39** (0.016)	-	392	.44
	-	-.46*** (0.001)	392	.44

Table 7 – Effect on turnover of the interaction between ETC and institutional entry costs: service industries only. ETC is measured over the period 1987-1997. Country and industry fixed effects are omitted.

A potential concern in this context is policy endogeneity. For example, it could be that entry costs vary across countries in a way that depends systematically upon rates of entry and exit in those countries. If for some reason firm turnover is suppressed in industries with high rates of ETC, incumbents may adopt higher entry costs to discourage competition. To assess this possibility, I instrument for entry costs using legal origin – see La Porta et al (1998). The results for the instrumental variables regression are even stronger: now all interaction terms are statistically significant, and their magnitude increases.

	ETC$\times EC^{DEA}$	ETC$\times EC^{WB}$	Obs	R^2
Turnover	-.75** (0.017)	-	719	.63
	-	-.50** (0.050)	719	.63
Entry	-.35* (0.061)	-	724	.62
	-	-.56* (0.074)	724	.61
Exit	-.38** (0.032)	-	721	.48
	-	-.66** (0.027)	721	.48

Table 8 – Effect on turnover of the interaction between ETC and institutional entry costs. Entry costs are instrumented using legal origin variables, obtained from the CIA World Factbook. ETC is measured over the period 1987-1997. Country and industry fixed effects are omitted.

ETC and EC are normalized by their means and standard errors. Hence, the coefficients can be interpreted as follows. According to the DEA measure of entry costs, Sweden is at the 25th percentile and Italy is at the 75th percentile. On the other hand, in terms of ETC, the 25th percentile is occupied by Transportation Equipment, whereas the 75th percentile is occupied by Retail Trade. In the median country, if entry costs were to drop from the level of Italy to the level of Sweden, the annual rate of turnover would converge between transportation equipment and retail trade by 0.17%, according to the instrumental variables regression.

The difference in annual turnover between the 25th and 75th percentiles is 2.9%. Thus, the interaction between entry costs and ETC is of roughly an order of magnitude below that of cross-industry variation in rates of entry and exit. This suggests that the ranking of industries according to turnover should not differ significantly across countries in spite of the differential effects of entry costs. Indeed, of the 153 possible country pairs, 82% of the correlations in rates of turnover are significant at the 10% level, 76% at the 5% level and 63% at the 1% level. Again, this is consistent with the premise that there are systematic differences in entry and exit rates across industries that have fundamental technological determinants.

6 Discussion

6.1 Other indicators of technical progress

The model prediction that turnover and ETC should be related is supported by the data. However, one may ask whether ETC might proxy for some other form of technological progress. In addition, the model has two predictions. One is that any form of technological progress that is embodied – even if it is not embodied in capital per-se – should be related to higher rates of turnover through a similar mechanism. The second is that DTC should not be related to entry and exit, except through mechanisms that are absent from the model.

The first prediction can be addressed as follows. Ilyina and Samaniego (2007) find that industries vary systematically in terms of R&D intensity, and that these differences are stable over the period 1970-2000. The knowledge generated by R&D should be embodied either in new products or in new processes at the innovating firm, which may be costly to adjust. If so, the model would suggest that R&D intensity should be positively related to entry and exit. To examine this, I constructed a measure of R&D intensity. Following Ilyina and Samaniego (2007), I used reported R&D expenditures divided by capital expenditures, as reported in Compustat, measured over the 1990s. The industry value is the value for the median firm in the sample.[11]

The second prediction is more difficult to address. Total factor productivity (TFP) is often interpreted as a measure of DTC, and one possibility would be to examine the relationship between TFP and turnover. I use the TFP measures of Jorgensen et al (2006).[12]

Nonetheless, such an exercise should be interpreted with caution for several reasons. First, it is not clear whether TFP is a "pure measure" of DTC. For example, an extensive literature relates cross-industry differences in TFP to R&D activity. In this

[11] Results were similar using R&D intensity measured over the 1980s, or using R&D intensity as measured by reported R&D spending divided by sales.

[12] Due to data availability, for this exercise I drop Rental Services and Other Services, and impute Waste disposal using the Jorgensen et al (2006) TFP values for Trucking and Warehousing, due to the composition of the industry: excluding it does not affect the results.

case, TFP would be positively related to turnover, just as ETC. In addition, Greenwood et al (1997) among others observe that if the prices used to compute TFP measures are not adjusted for input quality then the TFP measures may include, among other things, capital-ETC. In this case, again, TFP and ETC should behave similarly in regressions, and should be positively correlated amongst themselves.

Another potential difficulty with this exercise is the suggestion by Geroski (1989), among others, that technical progress that may be reflected in TFP may be an outcome *generated by* high rates of entry and exit in an industry. However, so long as TFP is measured in years prior to the rates of entry and exit, reverse causality should be correspondigly less of a concern. In addition, there is a sense in the productivity literature that TFP growth rates over the long term are primarily driven by the nature of knowledge applicable to each sector – see Ngai and Samaniego (2007) for a survey. In any case, under this hypothesis TFP (and possibly R&D) should behave much as ETC and possibly be collinear.

Finally, there are reasons to expect a negative relationship between TFP and turnover. Fisman and Sarria-Allende (2004) argue that entry and exit should be least impacted by entry costs in industries that have high entry barriers. If rapid technological progress may function as an entry barrier (see Geroski (1995)), one might expect entry and exit rates to be *negatively* correlated with TFP growth, and to interact *positively* with entry costs in equation (21), although this argument would presumably apply to ETC also. Another possibility relates to a phenomenon from which the model abstracts: structural change. Ngai and Pissarides (2007) show that if industries producing imperfect substitutes differ persistently in terms of TFP growth rates, then sectors with high rates of TFP growth should gradually shrink. In a model with entry and exit, this should show up as a comparatively low rate of entry, a high rate of exit, or both. It is not clear in this case whether TFP would interact with entry costs in equation (21), however, unless entry costs are able to decelerate the process of structural change itself.

	Hypothesis	Corr. with turnover	Interaction with EC
ETC	Hastens exit (this paper)	+	-
	Barrier to entry	-	+
	Reflects TFP, R&D	+ or -, collinear	+ or -, collinear
RND	Hastens exit (this paper)	+	-
	Response to entry	+, ETC collinear	-, ETC collinear
	Barrier to entry	-	+
	Reflects DTC	None	None
TFP	Hastens exit (via R&D)	+, R&D collinear	-, R&D collinear
	Hastens exit (not R&D)	+	-
	Response to entry	+, ETC collinear	-, ETC collinear
	Barrier to entry (via R&D)	-, RND collinear	+, RND collinear
	Barrier to entry (not R&D)	-	+
	Structural change	-	+ or none
	Reflects DTC	None	None

Table 9 – Hypotheses for interpretation of the empirical results.

The correlation between ETC and TFP is negative (-18%) and not statistically significant. The correlation between ETC and R&D is a neglible 5%. Thus, the ETC results do not appear to reflect a relationship with other forms of technical change as omitted variables. Second, it does not support the notion that a significant component of TFP (nor R&D) is a response to entry and exit, and thus that TFP and entry/exit are jointly determined. If it were, given that ETC is strongly related to turnover, one would expect a significant positive correlation between the alternative technological measures and ETC (as well as turnover). On the other hand, the correlation between TFP and R&D is 42% (0.005), suggesting that a portion of TFP does in fact reflect the output of research.

	R&D	TFP	ETC	Obs	R^2
Turnover	.06 (0.653)	-.26** (0.049)	0.62*** (0.000)	39	.51
Entry	.12 (0.362)	-.31** (0.019)	0.56*** (0.000)	39	.49
Exit	-.07 (0.627)	-.09 (0.557)	0.60*** (0.000)	39	.38

Table 10 – Regressions between turnover measures and technological measures. P-values are in parentheses. In all tables, one, two and three asterisks represent significance at the 10%, 5% and 1% levels respectively.

TFP is *negatively* correlated with total turnover and with entry. This is the opposite of what would be expected if TFP were in some way embodied, or if it were a response to pressure from entrants, although it is consistent with the notion of rapid technical progress as an exogenous barrier to entry. At the same time, it is interesting that TFP is not significantly correlated with exit, but only with entry, suggesting that TFP may not be related to *overall* turnover (entry *and* exit) as such. For example, another interpretation of this finding is that, if sectors with relatively high TFP growth rates shrink over time as suggested by Ngai and Pissarides (2007), at least part if this contraction occurs through decreases in entry rates, rather than via significant increases in exit rates.

It is likely that the R&D and TFP measures are noisy and, as a result, the differences-in-differences approach may be more informative. I now estimate

$$\begin{aligned} y_{i,c} &= \sum_c \alpha_c I_c + \sum_i \alpha_i I_i + \beta_{ETC} ETC_i \times EC_c \\ &\quad + \beta_{TFP} TFP_i + \beta_{R\&D} R\&D_i \times EC_c + \varepsilon_{i,c}. \end{aligned} \tag{22}$$

Several new results emerge from Tables 11-13. First, the results concerning ETC are robust to the inclusion of other forms of technical change. Second, R&D appears to interact with entry costs in the same way as ETC, consistent with the notion that R&D represents a form of technical change that is ultimately embodied, although the coefficient is usually smaller and the level of significance often lower. Third, there is little support for a relationship between TFP and firm turnover. There is a positive interaction between TFP and entry costs in the entry equation, but this is sensitive to whether or not R&D is also included and thus appears to be due to collinearity.

While the sign of the interaction is consistent with the hypothesis of technical change as a barrier to entry, one would expect the coefficient on R&D to share this sign, whereas it does not. This suggests that TFP is not a determinant of differences in industry turnover, or that it is related to a process (such as structural change) that does not interact with entry costs. These findings should be regarded tentatively, as there are measurement and endogeneity concerns that may be difficult to overcome, but the results are reported in the hope of encouraging further research in the area.

Entry cost	EC^{DEA}			EC^{WB}				
Variable	ETC	R&D	TFP	ETC	R&D	TFP	Obs	R^2
Turnover	-.57**	-.37*	.21	-	-	-	683	.63
	(.046)	(.059)	(.305)					
	-.63**	-	.057	-	-	-	683	.63
	(.028)		(.749)					
	-.62**	-.29*	-	-	-	-	683	.63
	(.031)	(.079)						
	-	-	-	-.51*	-.38**	.16	683	.63
				(.067)	(.021)	(.354)		
				-.56**	-	.00	683	.63
				(.039)		(.987)		
				-.54*	-.32**	-	683	.63
				(.051)	(.026)			

Table 11 – Effect on turnover of ETC, TFP and R&D intensity, interacting with institutional entry costs. Country and industry fixed effects are omitted.

Entry cost	EC^{DEA}			EC^{WB}				
Variable	ETC	R&D	TFP	ETC	R&D	TFP	Obs	R^2
Entry	-.27	-.21*	.23*	-	-	-	688	.62
	(.151)	(.092)	(.084)					
	-.30*	-	.14	-	-	-	688	.62
	(.096)		(.237)					
	-.32*	-.13	-	-	-	-	688	.62
	(.087)	(.246)						
	-	-	-	-.10	-.27***	.18*	688	.62
				(.601)	(.008)	(.092)		
				-.14	-	.07	688	.62
				(.455)		(.488)		
				-.13	-.20**	-	688	.62
				(.480)	(.033)			

Table 12 – Effect on entry of ETC, TFP and R&D intensity, interacting with institutional entry costs. Country and industry fixed effects are omitted.

Entry cost	EC^{DEA}			EC^{WB}				
Variable	ETC	R&D	TFP	ETC	R&D	TFP	Obs	R^2
Exit	-.30**	-.16*	-.00	-	-	-	685	.48
	(.044)	(.088)	(.971)					
	-.32**	-	-.07	-	-	-	685	.48
	(.026)		(.419)					
	-.29**	-.16**	-	-	-	-	685	.48
	(.035)	(.038)						
	-	-	-	-.41***	-.11	-.01	685	.49
				(.001)	(.160)	(.890)		
				-.43***	-	-.06	685	.49
				(.001)		(.439)		
				-.41***	-.11*	-	685	.49
				(.001)	(.089)			

Table 13 – Effect on exit of ETC, TFP and R&D intensity, interacting with institutional entry costs. Country and industry fixed effects are omitted.

6.2 Conclusion

This paper suggests that an important aspect of the firm lifecycle is the rate at which the firm's technology falls behind the industry frontier. To the extent that this varies systematically across industries, it should be reflected in cross-industry differences in entry and exit rates. I find evidence for this using the rate of productivity improvements in the capital used by the industry.

The determinants of entry and exit have in general remained somewhat of a puzzle. This paper shows that ETC may be an important factor, drawing a relationship between entry, exit and a factor that several authors have argued is central to the process of economic growth – see Greenwood et al (1997) and Cummins and Violante (2002). There is an extensive literature that studies the contribution of entry and exit to productivity change – see Bartelsman and Dunne (2000) for a survey. This paper addresses a complementary question: the effect that different forms of technological progress may have on entry and exit. By focusing on the distinction between embodied and disembodied technological progress, the paper harks back to a long-standing debate (Denison (1964), Hulten (1992)) regarding the correct view of how technological progress occurs, and whether it is of any quantitative significance. The results suggest that ETC is important for understanding cross-industry differences in lifecycle dynamics. Similarly, in a related model of the product lifecycle, Jovanovic and Tse (2006) argue that industries with a high rate of ETC may experience an earlier "shakeout."

The model does not consider the strategic response of incumbents to potential entry. This reflects the finding of Geroski (1995) that generally incumbents do not appear to respond to entry, and the results suggest that these channels are not necessary to make headway in understanding more about entry and exit. Nonetheless, it would be interesting to see how the rate of ETC might affect outcomes in an entry model with strategic behavior.

Although less tractable, it would be interesting to examine the role of ETC in other lifecycle models such as the Jovanovic (1982) model where entrants learn about their own aptitude over time. In this case, it is possible that ETC introduces an additional cost to waiting, something that could have welfare implications if there is some sense in which firms in industries with high rates of ETC exit "too early." In addition, Ngai and Pissarides (2007) find that industries with relatively high rates of technical progress may decline as a share of GDP. It would be interesting to explore the role that entry and exit might play in the process of structural change.

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A Proofs

The proof of Proposition 1 is a consequence of the propositions and lemmata below.
Proof of Proposition 2. The household's first order condition for investment implies that

$$\frac{r_x^i}{r_{x'}^j} = \frac{x'}{x} \tag{23}$$

This is because the return to capital must be equal and, since the cost of capital in terms of consumption is linear in x^{-1}, that means the return to a unit of capital must also be linear in x^{-1} for there to be investment (or disinvestment) in all types. Moreover it means that the interest rate depends only on the level of x, not on the industry. Thus, in particular,

$$r_{ix} = \frac{\bar{x}_{it}}{x} r_{\bar{x}_{it}} \tag{24}$$

or, for any technology $\tau < t$, from (23),

$$r_x^i = r_0 e^{-g_{ia}\tau\Delta} \tag{25}$$

so that capital is relatively more expensive to rent for plants with older technology. Note that τ here is defined as the date at which the firm's technology was on the frontier, and we can rewrite the firm's problem in those terms instead of in terms of x. ■

Proof of Lemmata 1, 2 and 3. Notice that production is a static decision. Thus

$$\pi(z_t, x_t) = \max_{n_t, k_t} \{A_{it} p_{it} z_t k_t^{\alpha_k} n_t^{\alpha_n} - r_{x,t} k_t - w_t n_t\} \tag{26}$$

$$n_t = \left(\frac{\alpha_n A_{it} p_{it} z_t k_t^{\alpha_k}}{w_t}\right)^{\frac{1}{1-\alpha_n}} \tag{27}$$

so, plugging in this result yields

$$\pi(z_t, x_t) = \max_{n_t, k_t} \left\{ C \left(p_{it} A_{it} z_t k_t^{\alpha_k}\right)^{\frac{1}{1-\alpha_n}} - r_0 e^{-g_i \tau} k_t \right\}$$

Let $\alpha = \frac{\alpha_k}{1-\alpha_n}$, $C = \left(\frac{\alpha_n^{\frac{\alpha_n}{1-\alpha_n}} - \alpha_n^{\frac{1}{1-\alpha_n}}}{w_t^{\frac{\alpha_n}{1-\alpha_n}}}\right)$. Then,

$$k_t = \left(\frac{\alpha C \left(p_{it} A_{it} z_t\right)^{\frac{1}{1-\alpha_n}}}{r_{x,t}}\right)^{\frac{1}{1-\alpha}} \tag{28}$$

Plugging this back in yields

$$\pi\left(z_t, x_t\right) = \left(p_{it} A_{it} z_t\right)^{\frac{1}{1-\alpha_n-\alpha_k}} \frac{C^{\frac{1}{1-\alpha}}}{r_{x,t}^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}}} \left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right] \tag{29}$$

Now, given that $r_x^i = r_0 e^{-g_i \tau}$, this becomes

$$\pi\left(z_t, x_t\right) = \left(p_{it} A_{it} z_t\right)^{\frac{1}{1-\alpha_n-\alpha_k}} \frac{C^{\frac{1}{1-\alpha}}}{\left(r_0 e^{-g_i \tau}\right)^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}}} \left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right] \tag{30}$$

Suppose labor is the numeraire. Then the value of an entrant must be constant over time, so that, if $\Delta\phi_i$ is the growth rate of p_{it} then

$$\phi_i = -g_i \alpha_k - \sigma_i, p_{it} = p_{i0} e^{-\Delta(\alpha_k g_i + \sigma_i)t} \tag{31}$$

Then, if $B_i = C^{\frac{1}{1-\alpha}} \left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right] \left(p_{i0} A_{i0}\right)^{\frac{1}{1-\alpha_n-\alpha_k}} r_0^{\frac{-\alpha_k}{1-\alpha_n-\alpha_k}}$,

$$\pi\left(z_t, \tau, t\right) = B_i z_t^{\frac{1}{1-\alpha_n-\alpha_k}} \left(e^{-\alpha_k g_i (t-\tau)}\right)^{\frac{1}{1-\alpha_n-\alpha_k}} \tag{32}$$

Let $a = t - \tau$ be the age of the firm's technology (with respect to the frontier). Then,

$$\pi\left(z_t, a\right) = B_i z_t^{\frac{1}{1-\alpha_n-\alpha_k}} e^{-\frac{\alpha_k g_i}{1-\alpha_n-\alpha_k} a} \tag{33}$$

or, setting $\gamma_i = \frac{\alpha_k g_i}{1-\alpha_n-\alpha_k}$,

$$\pi\left(z_t, a\right) = B_i s_t e^{-\gamma_i a} \tag{34}$$

Thus, here, firm profits depend only on z and on the distance from the industry frontier. With this under our belts, we can write the firm's problem recursively and divide through by B_i to obtain

$$\begin{aligned} V^i(a, s) \;=\; & e^{\Delta(r+\eta+\lambda)a} \max_T \left\{ \sum_{t=a}^{T} e^{-\Delta(r+\eta+\lambda)t} \left[s e^{-\gamma_i t} \quad + \left(1 - e^{-\Delta\eta}\right) E\left[V\left(t, s'\right)\right]\right] dt \right. \\ & \left. e^{\Delta(r+\eta+\lambda)a} e^{-\Delta(r+\eta+\lambda)T} E_s \max\left[E_s V^i(0)(1-E), V^i(0, s)\right] \right\}. \end{aligned} \tag{35}$$

which does not depend on the date, only on industry parameters. ■

Proof of Proposition 3. Corollary of Lemma 3 ■

Proof of Proposition 1. First consider the measure over firms at date t. It follows the transition equation

$$\begin{aligned}\mu_{t+\Delta}^{i}(S,T) &= \int_{(s,t-\Delta)\in(S,T)} e^{-\lambda\Delta}\varepsilon_i\psi(s)\,dt \qquad (36)\\ &+\int_{(s,t-\Delta)\in(S,T)} e^{-\lambda\Delta}e^{-\eta\Delta}\left(1-\Upsilon(s,t)\right)\left(1-X(s,t)\right)d\mu_t^i(s,t)\\ &+\int_s\int_{(s',t-\Delta)\in(S,T)} e^{-\lambda\Delta}\left(1-e^{-\eta\Delta}\right)\\ &\times\left(1-\Upsilon(s',t)\right)\left(1-X(s',t)\right)f(s'|s)\,d\mu_t^i(s,t)\\ &+I(0\in T)\int_{\substack{s\in S\\ t<\infty}} e^{-\lambda\Delta}e^{-\eta\Delta}\Upsilon(s,t)\left(1-X(s,t)\right)d\mu_t^i(s,t)\\ &+I(0\in T)\int_s\int_{(s',t-\Delta)\in(S,T)} e^{-\lambda\Delta}\left(1-e^{-\eta\Delta}\right)\\ &\times\Upsilon(s',t)\left(1-X(s',t)\right)f(s'|s)\,d\mu_t^i(s,t)\end{aligned}$$

where S is a borel subset of the type space over z (redefined in terms of s) and T is a subset of ages. Abusing notation somewhat, f and ψ are now redefined with respect to s rather than z.

This satisfies the requirements of Theorems 1 and 2 from Hopenhayn and Prescott (1992), so a fixed point μ^* exists and is unique, given a constant volume of entrants ε_i.

Set the numeraire $w_t = 1$. The consumer's solution implies that across goods i, $\frac{p_i c_i}{p_j c_j} = \frac{\omega_i}{\omega_j}$, so $p_i c_i = \omega_i s_c$ where s_c is total spending on consumption and the demand for each good i is

$$c_i = s_c \frac{\omega_i}{p_i} \qquad (37)$$

So whatever spending on consumption might be, the share of each good is fixed. Define

$$p_c \equiv \frac{s_c}{c} = \prod_{i=1}^{I} p_i^{\omega_i} \qquad (38)$$

Now in a BGP it must be that their income is growing. So, for constant labor, need $c_t^{-\theta} w_t / p$ to be constant over time, so

$$g_p = g_c^{-\theta} g_w \qquad (39)$$

so if w is the numeraire then

$$g_p = g_c^{-\theta} \qquad (40)$$

Recall that p_{it} drops over time at rate $-\phi_i$. Given a constant mass of firms μ_i^*, real output grows at rate $-\phi$, so this equation holds provided

$$c_{i0} = s_c \frac{\omega_i}{p_{i0}} \tag{41}$$

Now p_{i0} is given by the entry condition (7), so shares of consumption are given and

$$\begin{aligned} p_c &= \prod_{i=1}^{I} p_i^{\omega_i} && (42) \\ &= \left[\prod_{i=1}^{I} p_{i0}^{\omega_i} \right] e^{\sum_i \phi_i \omega_i \Delta t} && (43) \end{aligned}$$

so real consumption grows at a constant rate $\theta \sum_i \phi_i \omega_i \Delta t$, and the share of each type of good is constant and given by p_{i0}. Notice that the output of each firm is not linear in p_{i0} (it is strictly convex) so that this means that for any p_{i0} there is a unique mass of firms in that industry that can satisfy demand for a given value of consumption spending s_c. (which pins down the entry rates ε_i). Conversely, given a total mass of firms s_c and the distribution of firms over industries is given. Preferences are such that a constant share of income is invested, so it remains to check that income is constant (in units of labor) and that the labor market clears. Turning to the budget constraint, income in (in units of labor) is constant provided the measure over firms is constant. Income is linear in the total number of firms. Hence, the number of firms that clears the labor market is the equilibrium number, which leads to equilibrium values of income, spending, and all other variables as above. ■

Proof of Proposition 4. Without loss of generality assume $\eta = 0$. As $\Delta \to 0$, the firm's problem approaches the continuous time problem

$$\begin{aligned} V^i(a,s) &= \max_T e^{(r+\lambda)a} \left\{ \int_a^T e^{-(r+\lambda)a} s e^{-\gamma_i t} dt \right. && (44) \\ & \left. e^{(r+\lambda)a} e^{-(r+\lambda)T} W \right\}, \ W = V^i(0,s)(1-E) && (45) \end{aligned}$$

Although this is a continuous time problem, it can be approached using discrete time recursive methods. The first order conditions for T given W are

$$s e^{-\gamma_i T} = (r+\lambda) W.$$

so that T is decreasing in W. Suppose W is the payoff assuming that $\gamma_i = 0$. That is strictly larger than $V^i(0,s)(1-E)$, so the true solution (if it exists) necessarily has T larger than T^{**}, which is the solution to that problem.

Now imagine the same problem subject to $T \in [T^{**}, \infty)$, and write the Bellman equation

$$
\begin{aligned}
BV^{i}(0,s) &= \max_{T\in[T^{**},\infty)} \left\{ \int_0^T e^{-(r+\lambda)a} s e^{-\gamma_i t} dt \right. && (46)\\
& \left. e^{-(r+\lambda)T} W \right\},\ W = V^{i}(0,s)(1-E) && (47)
\end{aligned}
$$

where B is the Bellman operator. Blackwell's conditions are satisfied (because T is bounded) so B is a contraction and the problem has a unique solution.

Let T^{*} be the solution. Its derivative with respect to g satisfies

$$
-\gamma T_g - T = \frac{W_g}{W}
$$

Solving for W,

$$
\begin{aligned}
W\left[\frac{1}{1-E} - e^{-(r+\lambda)T}\right] &= \int_0^T e^{-(r+\lambda)a}\left[s e^{-\gamma_i t}\right] dt && (48)\\
W &= \frac{s\left[1-e^{-(r+\lambda+\gamma_i)T}\right]}{(r+\lambda+\gamma_i)\left[\frac{1}{1-E} - e^{-(r+\lambda)T}\right]} && (49)
\end{aligned}
$$

and

$$
W_g = \frac{-sTe^{-(r+\lambda+\gamma_i)T}(r+\lambda+\gamma_i) - s\left[1-e^{-(r+\lambda+\gamma_i)T}\right]}{(r+\lambda+\gamma_i)^2\left[\frac{1}{1-E} - e^{-(r+\lambda)T}\right]} \tag{50}
$$

So $T_g < 0$ if and only if

$$
T = \frac{Te^{-(r+\lambda+\gamma_i)T}(r+\lambda+\gamma_i) + \left[1-e^{-(r+\lambda+\gamma_i)T}\right]}{(r+\lambda+\gamma_i)\left[1-e^{-(r+\lambda+\gamma_i)T}\right]} \tag{51}
$$

or

$$
1 > \frac{e^{-(r+\lambda+\gamma_i)T}(r+\lambda+\gamma_i) + \frac{1}{T}\left[1-e^{-(r+\lambda+\gamma_i)T}\right]}{(r+\lambda+\gamma_i)\left[1-e^{-(r+\lambda+\gamma_i)T}\right]} \tag{52}
$$

As $g \to 0$, $T \to \infty$ so this becomes

$$
1 > \frac{e^{-(r+\lambda+\gamma_i)T}(r+\lambda) + \frac{1}{T}}{(r+\lambda)} = 0 \tag{53}
$$

so the condition is satisfied. More generally, the inequality implies

$$
\begin{aligned}
& (r+\lambda+\gamma_i)\left[1-e^{-(r+\lambda+\gamma_i)T}\right] && (54)\\
> \ & e^{-(r+\lambda+\gamma_i)T}(r+\lambda+\gamma_i) + \frac{1}{T}\left[1-e^{-(r+\lambda+\gamma_i)T}\right] && (55)
\end{aligned}
$$

$$
\begin{aligned}
(r+\lambda+\gamma_i)\left[1-2e^{-(r+\lambda+\gamma_i)T}\right] &> \frac{1}{T}\left[1-e^{-(r+\lambda+\gamma_i)T}\right] && (56)\\
T(r+\lambda+\gamma_i)\left[1-2e^{-(r+\lambda+\gamma_i)T}\right] &> \left[1-e^{-(r+\lambda+\gamma_i)T}\right] && (57)
\end{aligned}
$$

so define $\hat{T}$ as

$$
(r+\lambda+\gamma_i)\left[1-2e^{-(r+\lambda+\gamma_i)\tau}\right]\hat{T} = \left[1-e^{-(r+\lambda+\gamma_i)\tau}\right] \tag{58}
$$

If there exist g such that $T_g > 0$ then there must exists a g such that $T = \hat{T}$. However, the only solution to this equation is $\hat{T} = 0$, and T is always positive, so we have a contradiction. The remainder of the proof is to show that the steady state entry and exit rate is increasing in T^*. The exit rate as $\Delta \to 0$ is $\lambda + \lim_{\Delta \to +0} \tilde{\xi}(\Delta)/\Delta$, where the first element accounts for exogenous exit and $\tilde{\xi}(\Delta) = \frac{\varepsilon_i \int_{T^*-\Delta}^{T^*} e^{-\lambda T^*} dt}{e_{i\varepsilon}/\lambda}$, so that $\lim_{\Delta \to +0} \frac{\tilde{\xi}(\Delta)}{\Delta} = \lambda e^{-\lambda T^*}$. ■