Penn Institute for Economic Research
Department of Economics
University of Pennsylvania
3718 Locust Walk
Philadelphia, PA 19104-6297
pier@econ.upenn.edu
http://www.econ.upenn.edu/pier

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"Entry, Exit and Investment-Specific Technical Change"
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by

Roberto M. Samaniego

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Entry, Exit and Investment-Specific Technical Change

Roberto M Samaniego*

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Abstract

Using European data, this paper finds that (1) industry entry and exit rates are positively related to industry rates of investment-specific technical change (ISTC); (2) the sensitivity of industry entry and exit rates to cross-country differences in entry costs depends on industry rates of ISTC.

The paper constructs a general equilibrium model in which the rate of ISTC varies across industries and new investment-specific technologies can be introduced by entrants or by incumbents. In the calibrated model, equilibrium behavior is consistent with stylized facts (1) and (2), provided the cost of technology adoption is increasing in the rate of ISTC.

JEL Codes: D92, L26, O33, O41.

Keywords : Entry, exit, turnover, investment-specific technical change, entry costs, vintage capital, embodied technical change, lumpy investment.

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Contact: Department of Economics, George Washington University, 2115 G St NW Suite 340, Washington, DC 20052. Tel: +1 (202) 994-6153. Fax: +1 (202) 994-6147. E-mail: roberto@gwu.edu.

1 Introduction

Entry and exit rates differ significantly across industries. Over the period 1963-1982, Dunne, Roberts and Samuelson (1988) find that five-year entry rates in US manufacturing data range from 21 percent in Tobacco to 60 percent in Scientific Instruments. High-entry industries are high-exit industries, suggesting that entry and exit are largely due to the same industry-specific factors. At the same time, little is known about what these factors might be.

This paper finds a strong, positive link between industry entry and exit rates and the pace of technical progress in the capital goods that the industry uses – the rate of *investment-specific technical change* (ISTC). A significant fraction of entry and exit thus represents the introduction and replacement of capital-embodied technologies.

ISTC is also positively related to the proportion of enterprises in each industry that displays large investment outlays in a given year. That investment often occurs in "spikes" has been known since at least Doms and Dunne (1998), and the results link this pattern to the replacement of new capital-embodied technologies by incumbents. Furthermore, the decision of whether (or when) to exit appears sensitive to policy: in countries in which the cost of entry is high, rates of entry and exit are disproportionately suppressed in industries with high rates of ISTC.

To analyze these findings, the paper develops a general equilibrium model in which changing the vintage of capital used by a particular enterprise is costly. In the model, this vintage is termed a "*technology*", and an enterprise is a technology-manager pair. The manager accumulates expertise with a given technology over time, and at any date may choose to upgrade to a newer technology – at the expense of accumulated expertise, as in Jovanovic and Nyarko (1996). The manager may also choose to close the enterprise at any date – opting instead to open a new enterprise, or to work.

The model generates endogenous entry, exit, and investment spikes. Since adjusting the vintage of the capital at a given establishment is costly, technological improvements in the production of capital goods erode the profitability of incumbents, so that eventually they either close or invest in updated capital. Investment spikes are typically modelled using non-convex capital adjustment costs, as in Khan and Thomas (2008). In the current model, adjusting the quantity of capital is costless: instead, the process of technology adoption itself generates lumpy investment, as in Klenow (1998).

Equilibrium behavior along the balanced growth path of the model economy is consistent with the stylized facts relating turnover to ISTC. The decline in equilibrium profits as an enterprise falls behind the industry frontier is more rapid if the rate of ISTC is high so that, when only new enterprises may implement new technologies, equilibrium rates of entry and exit are positively related to the industry rate of ISTC. In a calibration of the model in which incumbents too may adopt new technologies, ISTC accounts for a significant proportion of the observed cross-industry variation in entry and exit rates. Rates of ISTC are positively linked to the prevalence of investment spikes, as updating occurs sooner when the rate of ISTC is high. Entry costs in the model also suppress turnover in high-ISTC industries, as in the data. Notably, the ability of the model economy to match the empirical magnitude of these relationships depends on a positive link between technological adoption costs and the rate of ISTC – as in, for example, Greenwood and Yorukoglu (1997).

A theoretical link between turnover and technical change dates back at least to Schumpeter (1934), and an empirical link is studied in Mueller and Tilton (1969), Geroski (1989) and Audretsch (1991). However, these authors do not consider the rate of technical change as a determinant of long term industry differences in turnover and, in particular, none of them raises *ISTC* as an influence on lifecycle dynamics. This paper uses entry and exit data from 18 European countries: most studies of entry and exit are limited to manufacturing data, and an additional contribution of the paper is that service and other industries are covered also.

The model extends the framework of Hopenhayn and Rogerson (1993) to allow for multiple industries and for technical progress. In a survey of entry and exit, Geroski (1995) reports little success in relating differences in turnover rates to industry characteristics, mostly measures of profitability or entry barriers. In a general equilibrium context, even when there are *no industry differences* in profitability nor entry barriers, the model shows that there can be significant differences in equilibrium turnover rates due to differences in lifecycle dynamics. Following Greenwood, Hercowitz and Krusell (1997) and Cummins and Violante (2002), ISTC is measured using the quality-adjusted relative price of capital used in each industry: however, these papers do not link ISTC to lifecycle dynamics.

Campbell (1998) argues that ISTC may affect the *cyclical* behavior of aggregate entry and exit, and Klenow (1998) studies the cyclicality of investment in a related model. Samaniego (2008) finds that turnover and ISTC are positively related in a calibrated one-sector general equilibrium model. However, none of these papers attempts to account for long term cross-industry differences in turnover – although Jovanovic and Tse (2006) develop a related model in which new industries with a high rate of ISTC experience an earlier wave of capital replacement.

Section 2 surveys the empirical relationship between entry, exit, and the rate of ISTC. Section 3 introduces the model, while Section 4 characterizes the equilibrium and Section 5 studies the relationship between ISTC and turnover in the model.

Section 6 concludes with suggestions for future work. All proofs are in the Appendix.

2 Evidence

We examine the empirical relationship between industry rates of enterprise turnover and industry rates of ISTC. We also relate the prevalence of establishment-level investment "spikes" to ISTC. Finally, we use cross-country data to examine whether the partial correlation between ISTC and turnover is sensitive to policies that make entry costly.

2.1 Data

We measure industry entry and exit rates using the Eurostat database. Eurostat data cover the universe of "enterprises" in the business registers of the member countries of the European Union, and are gathered by their national statistical agencies using a uniform methodology.[1] Previous research on entry and exit mostly focuses on manufacturing data, which produces less than half of GDP in industrialized economies. The Eurostat data provide a more complete view of entry and exit, covering all formal economic activity in the non-public, non-farm sector.

Annual rates of entry, exit and turnover are available for 18 countries over the period $1997-2004$. The variable $Entry$ is the proportion of enterprises active in a given year t that entered since year $t-1$, and the variable $Exit$ is the number of enterprises that closed between $t-1$ and t, divided by the number of enterprises active in year t. The variable $Turnover$ is the sum of these two variables. For most of the paper, entry exit and turnover are average annual rates over the sample period for each country-industry pair, to abstract from short term conditions and from possible delays in the reporting of entry and exit.[2]

The measure of ISTC is the annual rate of decline in the quality-adjusted price of capital goods used by each industry, as measured in the United States. Greenwood et al (1997) and Cummins and Violante (2002) show that, in a competitive environment with similar Cobb Douglas production functions for different goods, a decline in the price of one good compared to another reflects an improvement in the productivity with which the first good is produced relative to the second.

[1] The enterprise is equivalent to the concept of the "firm" used by the US Census Bureau. However, in Eurostat mergers and changes of legal form are not counted as entry, nor are temporary shut-downs counted as exit. See the Appendix for further details regarding measurement.

[2] Any delays are likely to be short: for example, in the UK enterprises are removed from the business register three months after the register is notified of their closure.

Cummins and Violante (2002) provide annual quality-adjusted price series for 26 types of equipment. These prices are divided by the official consumption and services deflator for each year, so that all capital goods prices are expressed relative to the price of non-durables. The industry rate of ISTC is the annual rate of decline in the relative price of capital goods used by that industry. This is computed by weighting the declines in the individual good prices using annual capital expenditure shares for each industry, as reported in the Bureau of Economic Analysis (BEA) industry-level capital flow tables.

Country	Turnover	Entry	Exit
Belgium	14.2	7.2	7.0
Czech Republic	18.5	9.8	8.7
Denmark	17.4	9.4	8.0
Spain	15.1	8.9	6.2
Italy	15.1	7.9	7.2
Latvia	25.4	15.0	10.4
Lithuania	20.7	12.1	8.6
Hungary	21.1	11.6	9.5
Netherlands	17.1	8.9	8.2
Portugal	13.4	7.6	5.8
Slovenia	13.6	7.5	6.1
Slovakia	22.8	10.7	12.1
Finland	14.1	7.5	6.6
Sweden	11.1	5.9	5.1
United Kingdom	21.6	11.1	10.5
Romania	25.6	16.8	8.8
Norway	19.4	10.6	8.8
Switzerland	8.0	3.5	4.5
Europe	17.3	9.5	7.8

Table 1 – Summary statistics: Average annual rates of turnover across countries 1997-2004. The value for Europe is the average across countries, weighted by the number of enterprises in each. Source – Eurostat.

The ISTC measure can be constructed with or without structures as an additional capital type. The benchmark results include structures, and results using only equipment goods are reported for robustness. We use the official price series for structures when we include them, following Cummins and Violante (2002).

To control for potential simultaneity or lags in the ISTC-turnover link, the industry ISTC rate is the average over the period $1987 - 1997$, the decade prior to the measurement of entry and exit rates. For robustness, we also consider average ISTC over the entire post-war period $1947 - 2000$. The correlation between the two series is 0.91, supporting the interpretation of the rate of ISTC as a long-term industry characteristic.

The BEA capital flow tables use the NAICS industry classification system, whereas Eurostat uses the NACE 1.1 system. The paper reports results for 41 industries, representing the join of the two systems. Rates of ISTC range from about 1.14 percent for Oil and Gas extraction to 8.33 percent for Air Transport. The median industry rate is 4.02 percent.

"Investment lumpiness" is measured using US data from Compustat. Over the period 1997-2004, I identify whether each firm in the database experiences an investment "spike." Doms and Dunne (1998) define a spike as an increase in the capital stock of 30 percent or more within a year. The index *Lumpy* for industry j is the proportion of firms in j that experienced any "spikes" over the period.[3] Compustat covers all publicly traded firms in the US so that, while not being a representative sample of US firms, firms in Compustat are likely to be financially unconstrained, so that their behavior reflects fundamentally technological factors. Values range from about 0.05 in Utilities to 0.95 in Systems Design.

The unit of observation in Compustat is the firm, so that updating at multi-plant firms may not be detected if the updating is not synchronized. Hence, lumpiness is also computed for smaller firms only. The disadvantage of the size-based measures is that there are very few firms in Compustat in some industries below certain size thresholds, so these measures are likely to be noisy.

Some of the regressions require country-level measures of entry costs. I use the cost of starting a business as a proportion of GDP per capita, as reported in Djankov, La Porta, Lopez-de-Silanes and Shleifer (2002), denoted EC. Entry costs are determined by studying the laws and regulations of entry in each country, identifying required procedures and computing the cost of complying with each. For international comparability, and to focus on the costs of entry per se, the procedures considered are those that apply to a "standardized entrant", defined as one that is not subject to any special exemptions, is not in a highly regulated industry (such as tobacco or finance), does not trade internationally, is domestically owned, operates in the most

[3] "Investment" is DATA128 (capital expenditures) and "capital stock" is DATA8 (net property, plant and equipment). The median annual industry value of this variable across manufacturing industries is 6 percent, strikingly similar to the value reported by Doms and Dunne (1998). Data were not available for Educational Services nor for Other Services.

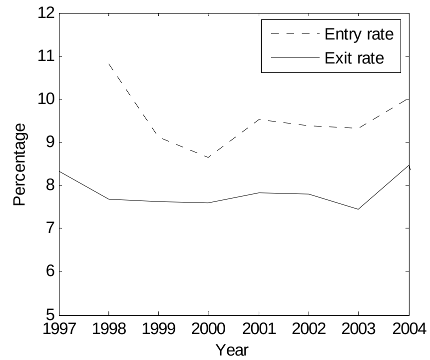

Figure 1: Variation over time in average entry and exit rates in Europe, 1997-2004, based on Eurostat. Countries are weighted by the number of enterprises in each. Eurostat does not report entry rates for 1997. Time variation is small relative to variation across countries and industries, as seen in Table 2.

populous city, does not own real estate and is of medium size. For further details see Djankov et al (2002) and World Bank (2006).

The maintained assumption is that the rate of ISTC (or the ranking) is an industry characteristic that persists across countries. This amounts to assuming similar input-output tables and similar rates of technical progress in any given type of capital good across countries. Since the median rate of ISTC is about 4 percent per year, it is unlikely that significant differences in ISTC for the same industry across countries could be sustained for long in the absence of draconian import restrictions.

2.2 Turnover and ISTC in cross-section

Table 1 reports average entry and exit rates across Europe, and Figure 1 plots their behavior over time. Time does not appear to be an important source of variation in the data. Indeed, analysis of variance indicates that about half of turnover and entry, and about 40 percent of exit, are attributable to variation across industries and countries only – see Table 2.

Variable	Industry	Country	Time	Residual	Obs
Turnover	0.221	0.274	0.011	0.494	2661
Entry	0.249	0.206	0.013	0.531	3197
Exit	0.118	0.204	0.018	0.660	3027

Table 2 – Analysis of variance (ANOVA) for turnover, entry and exit rates. Roughly a quarter of turnover can be attributed to variation across industries, and another quarter to variation across countries.

Define *industry* rates of turnover, entry and exit as the industry fixed effect in a regression of turnover on industry and country dummies.[4] The correlation between entry and exit rates is 0.67, whereas between turnover and entry it is 0.96, and between turnover and exit it is 0.85.[5] Of the 153 possible country pairs in the database, 76 percent of the cross-country correlations in rates of turnover are significant at the 5 percent level. This indicates that entry and exit rates in a given industry in different countries may have common, possibly technological, determinants.

	ISTC coefficient	
	With structures	Without structures
Turnover	1.24*** (0.326)	1.89*** (0.305)
Entry	0.81*** (0.240)	1.28*** (0.229)
Exit	0.43*** (0.122)	0.61*** (0.124)

Table 3 – Coefficients of a regression of turnover on ISTC. Standard errors are in brackets. The link between ISTC and turnover is positive and significant. In all tables, one, two and three asterisks represent significance at the 10, 5 and 1 percent levels respectively.

The data suggest that ISTC may be one of these determinants. Table 3 reports coefficients for bivariate regressions of industry rates of industry rates of entry and

[4] We report this rather than cross-country averages because of a small number of missing observations (for example, 14 out of 738 observations are missing for entry).

[5] The correlation between entry and exit rates reported in Dunne et al (1988) for US manufacturing industries is 0.74. Brandt (2004) finds a similar relationship in OECD data and in an earlier edition of Eurostat which, as here, includes services.

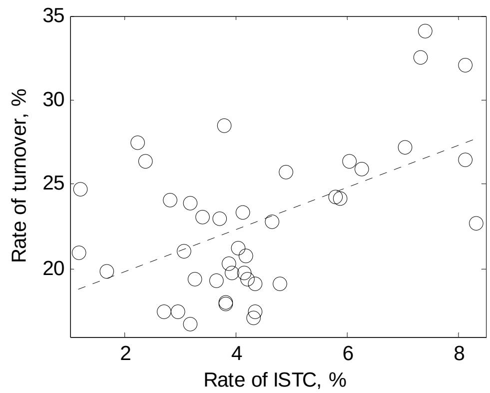

Figure 2: Cross industry comparison of turnover and ISTC. The dotted line represents fitted values using the turnover coefficient in the first column of Table 3.

exit on ISTC. Strikingly, Table 3 and Figure 2 report that these rates are very highly correlated. This is true of manufacturing industries and also of non-manufacturing industries, which report correlations with turnover of 0.45 and 0.56 respectively. Correlations are even stronger for the ISTC measure that excludes structures. The effects are large: a 1 percent increase in ISTC is associated with a 1.24 percent increase in the annual rate of turnover. It is worth noting that, using industry turnover rates at the level of individual countries instead of industry fixed effects, the coefficient on ISTC is significant at the 5 percent level in 14 of 18 cases.

These findings suggest that entry and exit represent, at least in part, the introduction and abandonment of capital-embodied technologies. However, capital may be introduced at *continuing* enterprises as well as new ones. The replacement of a large proportion of the capital stock at a given enterprise is likely to coincide with an investment spike, and we might expect as a result that industries with higher rates of ISTC might display more investment spikes. Indeed, Table 4 shows that the index *Lumpy* is positively and significantly correlated with entry, exit and ISTC. This is regardless of whether *Lumpy* is computed using all firms in Compustat, or only those below a certain size thresholds. A 1 percent increase in the rate of ISTC leads to a 3.8-5.3 percent increase in the prevalence of investment spikes.

2.3 Interacting ISTC with entry costs

The costs imposed by the regulation of entry are known to vary significantly across countries. Cross-country differences in industry behavior and the regulation of entry may provide further insight into the determinants of turnover – and, in particular, into whether technological diffusion through turnover is sensitive to policy.

For entrepreneurs, the opportunity cost of operating an enterprise includes the value of closing the enterprise and opening a new one. If the institutionally imposed cost of entry is high, the value of incumbency increases relative to the value of new entry. If entry and exit reflect the introduction and replacement of technologies, entrepreneurs may avoid a high entry cost entirely by adopting new technologies at existing enterprises instead of exiting. Hence, we might expect entry costs to reduce rates of exit disproportionately in industries in which the rate of ISTC is high. To the extent that turnover is a long-run phenomenon, rates of entry, and of overall turnover, should also be especially sensitive to entry costs in high-ISTC industries.

Size	Turnover	Entry	Exit	ISTC
All firms	2.41***	3.11***	6.04***	5.32***
	(0.748)	(1.072)	(2.056)	(1.851)
Under 500	1.98**	2.69**	4.73**	5.09***
	(0.765)	(1.089)	(2.135)	(1.847)
Under 250	1.57**	2.40**	2.88	3.84**
	(0.774)	(1.086)	(2.202)	(1.874)

Table 4 – Bivariate regressions of lumpiness on turnover and ISTC. "Lumpiness" is the share of firms in Compustat experiencing an investment spike during the period 1987-1997. The column "Size" indicates whether a threshold was imposed on the number of employees at the firms used to compute the lumpiness index. The link between lumpiness and ISTC (as well as turnover) is positive and significant.

To test for these patterns, I adopt the differences-in-differences approach pioneered by Rajan and Zingales (1998). Let $y_{j,c}$ be entry, exit or turnover for industry j in country c. Variable $ISTC_j$ measures the rate of ISTC in industry j, and EC_c measures entry costs in country c. Then, estimate the equation:

$$y_{j,c} = \delta_j + \alpha_c + \beta.ISTC_j \times EC_c + \nu_{j,c} \quad (1)$$

In equation (1), α_c and δ_j capture all country- and industry-specific factors affecting entry and exit rates . If entry costs reduce enterprise turnover disproportionately in high- ISTC industries, the coefficient β on the interaction term $ISTC_j \times EC_c$ should be *negative*.

Industries included	Turnover measure	Interaction coefficient β	Obs	R^2
All industries	Turnover	-0.68*** (0.254)	719	0.34
	Entry	-0.31** (0.140)	724	0.31
	Exit	-0.37** (0.150)	721	0.30
Manuf. only	Turnover	-1.31*** (0.439)	283	0.52
	Entry	-1.00** (0.418)	284	0.42
	Exit	-0.39** (0.153)	284	0.46
Non-Manuf.	Turnover	-0.67** (0.255)	436	0.34
	Entry	-0.29* (0.144)	440	0.32
	Exit	-0.38** (0.151)	437	0.28

Table 5 – Effect on turnover of the interaction between ISTC and entry costs. Country and industry fixed effects (α_c, δ_j) are omitted for brevity. Standard errors are reported in brackets, and allow for correlated errors across countries within an industry. Coefficients are negative and significant in all cases, indicating that entry costs disproportionately lower turnover in industries with high rates of ISTC.

The coefficient on the interaction term between ISTC and entry costs is negative and significant – see Table 5. This is regardless of whether turnover, entry or exit is the dependent variable in the regression, indicating that *policy can delay technological diffusion through turnover.*

To get a sense of the magnitude of these coefficients, consider the following. The country with the lowest entry cost is the UK (5.6 percent of GDP per head), and the highest is Hungary (81 percent). The coefficients imply that the difference in entry rates between the industries with the highest and lowest rates of ISTC in Hungary is about 6.6 percent smaller than in the UK. Since industry rates of entry vary from about 0.09 to about 0.21, this represents a substantial difference – although not large enough to overturn the positive relationship between ISTC and turnover.

Specification	Turnover measure	Interaction coefficient β	R^2
Baseline spec., ISTC measured over 1947-2000.	Turnover	-0.56** (0.261)	0.34
	Entry	-0.23* (0.127)	0.30
	Exit	-0.33* (0.165)	0.29
Baseline spec., ISTC measured without structures.	Turnover	-0.54** (0.228)	0.34
	Entry	-0.27* (0.136)	0.31
	Exit	-0.25* (0.134)	0.29
Baseline spec., industry dummies constrained to be a linear function of ISTC.	Turnover	-0.68*** (0.252)	0.49
	Entry	-0.31** (0.140)	0.45
	Exit	-0.37** (0.149)	0.37

Table 6 – Effect on turnover of the interaction between ISTC and entry costs. Country and industry fixed effects (α_c, δ_j) are omitted for brevity. Standard errors are reported in brackets, and allow for correlated errors across countries within an industry. Coefficients are all negative and mostly significant, indicating the robustness of the results from Table 5 to different specifications and approaches to measuring ISTC.

It is interesting to check the robustness – or generality – of the results by seeing whether they hold if manufacturing and non-manufacturing industries are treated separately. While standard errors are larger, the inference does not change.

Repeating the regressions with ISTC measures from the entire post-war period yields much the same results, consistent with the hypothesis that ISTC is a long-run industry characteristic related to entry and exit rates. See Table 6. Results are robust to measuring ISTC with and without structures.[6] Results are also broadly similar when the industry dummies are constrained to be a linear function of ISTC ($\delta_j = \delta.ISTC_j$), reflecting the importance of ISTC for industry indices of turnover. Finally, replacing the Djankov (2002) measure of entry costs with the World Bank (2006) update of this measure did not change the results.

3 Economic Environment

This section develops a general equilibrium model with entry and exit, to assess to what extent a vintage-style framework can account for the above findings. As we shall see, the positive link between ISTC and turnover features in a relatively simple vintage setup. However, reproducing the interaction of ISTC with entry costs requires a richer model, in which exit is not the only option facing an enterprise with an obsolete technology.

In the model, a continuum of enterprises of endogenous mass live in continuous time. An enterprise is a technology, implemented by a manager/entrepreneur with a degree of success that is stochastic yet persistent. The model thus features heterogeneity among enterprises of the same vintage, so that exit is not programmed simply by the date of birth.

In the model, a technology is a *level* of investment-specific technical change. The capital sector converts the aggregate good into capital goods, and the efficiency of capital production differs by industry and by technology. This allows the relative price of capital to decline over time at industry-specific rates that reflect the rate of ISTC, as assumed in Section 2. Entrepreneurs may update the vintage of their technology: however, updating may decrease their expertise, part of which is vintage-specific. Also, at any point, the manager may choose to close the enterprise if the payoff from her outside option exceeds that of continuation. As a result, entrepreneurs may find it optimal to be temporarily "locked" into a particular technology, investing in capital behind the industry frontier until eventually they update or exit.

[6] Interestingly, results are also similar if $ISTC_j$ is replaced with "lumpiness."

3.1 Households and investment

Time is indexed by t. Aggregate good y_t is a composite of the output of J industries:

$$y_t = \prod_{j=1}^{J} \left(\frac{y_{jt}}{\omega_j} \right)^{\omega_j}, \omega_j > 0, \sum_{j=1}^{J} \omega_j = 1. \tag{2}$$

It can be used for consumption c_t or for investment $i_j(x,t)$ in capital goods for any industry j of type x. Index x is a level of investment specific technical change. The stock of each type of capital evolves according to

$$\frac{\partial k_j(x,t)}{\partial t} = i_j(x,t)\, x - \delta k_j(x,t) \tag{3}$$

where δ is the depreciation rate of capital. The index x gives the units of capital produced from converting one unit of foregone consumption: disinvestment is also possible at this rate. There is a frontier level of x which varies by industry, denoted $\bar{x}_{jt}$. It changes over time at rate g_j, so that $\bar{x}_{jt} = \bar{x}_{j0} e^{g_j t}$. Parameter g_j is the rate of investment-specific technical change experienced by industry j.

The rate of time preference is ρ. Preferences over consumption streams are

$$\int_0^{\infty} e^{-\rho t} c_t dt. \tag{4}$$

Each agent at time t holds $k_j(x,t)$ units of capital of type x for industry j. Each capital type commands a rental rate $r_j(x,t)$. Agents are also endowed with one unit of labor at each date t, which may be used to earn a wage w_t or used in entrepreneurship. An agent raises income by renting capital and labor to enterprises, and by earning profits π_t from enterprises she owns if the agent is an entrepreneur. She may also receive lump sum transfers λ_t.

The budget constraint is

$$p_t c_t + p_t I_t \leq w_t + R_t + \pi_t + \lambda_t \tag{5}$$

where I_t is total investment spending and R_t is total capital income. Agents select consumption, investment and labor allocations so as to maximize (4), subject to (5).

3.2 Production

Each enterprise is characterized by a technology x, and the manager's success in implementing it z_t, as well as its industry j: its *type* is the triple (x, z, j). The enterprise's production function is

$$A_{jt} z_t k_t^{\alpha_k} n_t^{\alpha_n}, \ \alpha_k + \alpha_n < 1 \tag{6}$$

where k_t is the quantity of efficiency units of capital that it uses, and n_t is labor. Disembodied technology in the model is $A_{jt} = A_{j0} e^{\kappa_j t}$. Thus, g_j is the industry rate of investment-specific technical change (ISTC), and κ_j is the industry rate of disembodied technical change (DTC).[7]

Technology adoption is costly. At the end of any period, the enterprise may choose to update its technology x to the frontier, retaining only a proportion $\zeta < 1$ of its prior expertise z. Thus, some accumulated knowledge may no longer apply to the new technology.

Several authors have pointed out that higher rates of ISTC are likely related to higher adoption costs.[8]. Hence, let $\zeta = \zeta(g_j)$, $\zeta'(\cdot) \leq 0$.

At Poisson rate η enterprises obtain a new level of productivity z', drawn from a cumulative distribution $f(z'|z)$ with support $z' \in [z_l, z_h]$, $z_l \geq 0$, $z_h < \infty$. Otherwise, z remains constant (unless x is updated).

3.3 Entry and Exit

Agents in this environment may either work, or create and operate an enterprise. Creating an enterprise requires a delay of length d before production begins. The technological cost of entry is $E^T = 1 - e^{-\rho d}$, expressed as a share of expected discounted profits. In addition, startup procedures may impose costs equivalent to a proportion E^C of the expected profits. The proceeds from E^C are redistributed as a lump sum to the households.

Define $E = E^T + E^C$. Note that E fits the definition of an entry barrier in McAfee, Mialon and Williams (2004) of a sunk cost that incumbents avoid but entrants do not. The formulation of E^T as a delay captures the concept of "time to build" in Kydland and Prescott (1982), while E^C reflects the finding of Djankov et al (2002) that the regulation of entry imposes costs on entrepreneurial activity.

Enterprises start their lives with a value of z_t drawn from a distribution ψ, and with the frontier technology. The opportunity cost of entrepreneurial labor is U_t,

[7] Although x does not enter the production function, it affects profits because it is the rate at which the economy can produce the capital goods that the enterprise uses, which is reflected in the equilibrium rental rate of capital. In equilibrium, more efficient technologies will be associated with cheaper capital, providing an incentive to use the frontier technology.

[8] See Greenwood and Yorukoglu (1997), Greenwood and Jovanovic (2001) and Bessen (2002). In a one-sector general equilibrium model, Samaniego (2008) finds that allowing adoption costs to respond to the rate of ISTC can be important for its impact on technology adoption decisions.

to be discussed in more detail below. At any point in time, the entrepreneur may close the enterprise, also earning a continuation payoff U_t. Once born, enterprises also close exogenously at Poisson rate χ. Upon exit, entrepreneurs may work in any industry, or open another enterprise. That entrepreneurs are not tied to any particular industry and move in and out of the labor market is consistent with the behavior documented by Lazear (2005).

4 Equilibrium

The competitive price of good j is p_{jt}. The enterprise's profits at time t equal

$$\pi_j(x, z_t) = \max_{k_t, n_t} \{A_{jt} p_{jt} z_t k_t^{\alpha_k} n_t^{\alpha_n} - r_j(x,t) k_t - w_t n_t\} \tag{7}$$

where $r_j(x,t)$ is the equilibrium rental rate of capital of type x in industry j.

In equilibrium, entrepreneurship in any sector experiencing entry must carry the same expected benefit as working. The return from entrepreneurship is stochastic: however, agents are risk neutral.[9] Hence, in equilibrium,

$$U_t = \max_{j \leq J} \int V^j(\bar{x}_{jt}, z_t) \psi(z_t) dz_t (1 - E) \tag{8}$$

where $V^j(x, z_t)$ is the value of an enterprise of type (x, z_t), described below. Note that V^j includes the discounted value of closing the firm and, if it is profitable to do so, returning to the labor market.

Let ε_{jt} be the mass of entrants at date t. If in equilibrium there is entry into any two sectors j and j', it must be that

$$\int V^j(\bar{x}_{jt}, z_t) \psi(z_t) dz_t = \int V^{j'}(\bar{x}_{j't}, z_t) \psi(z_t) dz_t \tag{9}$$

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

If agents work, they earn a flow of income w_t. Since entrepreneurs must decide between working and starting enterprises, the expected value of starting a enterprise equals the value of remaining in the labor force:

$$U_t = \int_0^\infty e^{-\int_0^\tau \iota(s+t)ds} w_{t+\tau} d\tau, \tag{10}$$

[9] With more general preferences, assuming complete insurance markets would imply that there is no income uncertainty for individual agents, leading to the same result.

where $\iota(t)$ is the interest rate at date t.

Each enterprise has a name $m \in \mathbb{R}$, representing its unique entry in the business register. Employment at enterprise m is $n(m)$, and the measure of active enterprises[10] at date t is μ_t. The number of entrepreneurs is $\int d\mu_t$, so feasibility requires that

$$\int d\mu_t + \int n(m)\, d\mu_t \leq 1 \tag{11}$$

The set of enterprises in operation in industry j at date t is M_{jt}. Define for any two dates t, t'

$$\Xi_{t,t'} = \{m : m \in M_{jt}, m \notin M_{j,t'}\} \tag{12}$$

Thus, for $\Delta > 0$, $\Xi_{t-\Delta,t}$ is the set of enterprises that exited between time $t - \Delta$ and t, whereas $\Xi_{t,t-\Delta}$ is the set of enterprises that entered between those dates. If $\mu_t(X)$ is the measure of any set $X \subseteq M_{jt}$ of enterprises, the *share* of enterprises that do not reach time t is $\frac{\mu_{t-\Delta}(\Xi_{t-\Delta,t})}{\mu_t(M_{jt})}$, and the share of enterprises at time t that were born since time $t - \Delta$ is $\frac{\mu_t(\Xi_{t,t-\Delta})}{\mu_t(M_{jt})}$.

Definition 1 *Industry rates of entry and exit are:*

$$Entry_t = \lim_{\Delta \to 0} \frac{\mu_t(\Xi_{t,t-\Delta})}{\mu_t(M_{jt})} \times \frac{1}{\Delta} \tag{13}$$

$$Exit_t = \lim_{\Delta \to 0} \frac{\mu_{t-\Delta}(\Xi_{t-\Delta,t})}{\mu_t(M_{jt})} \times \frac{1}{\Delta} \tag{14}$$

Definition 2 *A stationary equilibrium or balanced growth path (BGP) is a measure μ^*, a mass of entrants ε_j^* for each industry and time paths for prices p_{jt}^* such that the labor market clears, the measure replicates itself, all households maximize* (4) *subject to* (5) *given prices and expectations, and aggregate output y_t grows at a constant rate.*

This definition is similar to that in Hopenhayn and Rogerson (1993) except that this model distinguishes between industries. Also, because rates of investment-specific and disembodied technical change differ across industries, relative prices will diverge along a balanced growth path, as in Greenwood et al (1997).

[10] The law of motion for μ_t is an equilibrium object. An explicit treatment of the law of motion would complicate the presentation without adding any new insights and is available from the author upon request. For μ_t to be stationary in equilibrium, later it will be convenient to redefine the establishment's type in terms of the *age* of its technology rather than its level x.

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

The proof works as follows. An equilibrium with entry into all industries requires the expected value of entry to be equal to the discounted value of working forever (10). Along a BGP this value is stationary, so the decision problem of the entrepreneur must be stationary too, implying that optimal decision rules are constant over time. Given a constant flow of entrants ε_j into each industry j, the stationary measure of enterprises in each industry can be computed using the optimal decision rules. Cobb-Douglas preferences imply constant expenditure shares, pinning down *relative* industry sizes (and hence relative values of ε_j): only the *scale* is unknown. The proof shows that there is a unique constant scaling factor that clears the labor market.

Proposition 2 *Along a balanced growth path,* $r_j(x,t) = (\rho + \delta)/x$.

This result is central to enterprise dynamics in the model. Enterprises using more advanced capital than their competitors benefit through cheaper capital services. On the other hand, the fact that updating is costly implies that enterprises gradually fall away from the frontier, whereas some of their competitors – either because they just updated or because they are recent entrants – may use more advanced capital than they do. The price of industry output declines along with the average cost of production across the industry, whereas any *given* enterprise only benefits from decreased costs if it updates. As a result, g_j introduces a downward trend in the marginal revenue product of each enterprise, net of other aspects of enterprise dynamics.

This intuition suggests that rates of entry and exit may not be related to the industry rate of *disembodied* technological progress κ_j, since it is *not* costly to adjust. The price of output declines at a rate that offsets DTC. However, since all enterprises are at the frontier with respect to DTC, this has no influence on their lifecycle decisions.

Establishment types can be re-specified in terms of the *age* of their technology a, rather than its level x. This recasting is convenient as, in a stationary equilibrium, the behavior of establishments of the same age will be similar regardless of the date.

Lemma 1 *On a balanced growth path, an enterprise's updating and exit decisions depend only upon parameters indexed by industry* j *and the age of technology* a*, not the date.*

At any date, the entrepreneur's problem can be represented recursively, and written in terms of the technology's age a instead of the level of ISTC x.

To analyze the entrepreneur's decision problem, consider a simple case in which:

Assumption 1 Productivity $z \in \{0,1\}$, $\zeta = 0$, and $z = 0$ is an absorbing state.

Under this assumption there is only one positive value of the shock z, and there is no updating. Solving for optimal input use, the enterprise's exit behavior is the solution to an optimal stopping problem of the form:

$$rV^j(a,z) = \pi_j(a,z) + \frac{\partial V^j(a,z)}{\partial a} + \chi\left[U - V^j(a,z)\right] \tag{15}$$

subject to the boundary condition

$$V^j(a,z) \geq U. \tag{16}$$

The value $V^j(a,z)$ can be interpreted in terms of a put option with strike price U. The owner earns profit flow $\pi^j(a,z)$, and experiences a capital gain $\frac{\partial V^j(a,z)}{\partial a}$ (which is negative) due to the fact that the profit flow declines with age. At any point in time, the owner may close the enterprise, in which case she earns U but gives up the ability to earn $V^j(a,z)$ in the future. Finally, the owner may be *forced* to exercise the option at Poisson rate χ.

Allowing for updating and for uncertainty, the enterprise's exit behavior is the solution to:

$$\begin{aligned} rV^j(a,z) &= \pi_j(a,z) + \frac{\partial V^j(a,z)}{\partial a} + \chi\left[U - V^j(a,z)\right] \\ &\quad + \eta\int\left[V^j(a,z') - V^j(a,z)\right]df(z'|z) \end{aligned} \tag{17}$$

subject to the boundary conditions

$$V^j(a,z) \geq U \text{ and } V^j(a,z) \geq V^j(0,z\zeta). \tag{18}$$

Equation (17) differs from (15) in that z is stochastic, and that the option to update implies an additional boundary condition.

Denote by $T^*(z)$ the age at which the technology becomes obsolete – the age at which either the option to exit or to update are exercised. Let $\Upsilon^*(z) \in \{0,1\}$ equal one if the enterprise optimally updates, and let $X^*(z) \in \{0,1\}$ equal one if the enterprise optimally exits.

Equilibrium lifecycle dynamics are straightforward. An enterprise is born, and experiences productivity shocks while falling behind the technological frontier. Eventually, at age $T^*(z)$, the enterprise either updates or – if z_t is sufficiently low – closes.

The industry-specific parameters that might affect lifecycle dynamics are g_j (the rate of ISTC), κ_j (disembodied technical change), A_{j0} (initial productivity) and ω_j (preferences). Notice that, combining (8) and (10), U can be written in terms of V^j so that the solution to problem (17) does not depend on industry variables that enter multiplicatively, such as A_{j0} and ω_j (which enters through prices). Also, disembodied technical progress is offset by declining prices, so that profits are independent of κ_j. As a result:

Proposition 3 *Along a BGP, optimal entry and exit rules depend on g_j, but do not depend on κ_j, A_{j0}, nor ω_j.*

5 ISTC and model industry dynamics

This section has several objectives. In a simple version of the model without updating, equilibrium entry and exit rates are proven to be positively related to g_j. Then, in a calibration of the general model to US data, simulations indicate that entry and exit rates are positively related to g_j even when updating is allowed. In addition, enterprises in the calibrated model turn out to display investment spikes when they update, and the presence these spikes is also positively linked to g_j. Entry costs also compress rates of entry and exit across industries with different rates of ISTC. Thus, lifecycle dynamics in the calibrated model are consistent with all the empirical findings in Section 2.

5.1 Entry and exit in a simple vintage capital model

To characterize the impact of ISTC on the timing of exit, for now let Assumption 1 hold, so there is no updating and the value function reduces to (15). As in a typical vintage capital model, only entrants have access to the frontier technology. This focuses the model on *when*, rather than *whether*, to exit.

Proposition 4 *Under Assumption* 1*, T^* is strictly decreasing in g_j, and rates of entry and exit are strictly increasing in g_j.*

Corollary 1 *Under Assumption* 1*, rates of entry and exit are strictly increasing in the rate of decline in the relative price of capital used by each industry.*

Two effects impact whether high g_j involves earlier exit. Enterprises fall behind the frontier at a rate that depends on g_j, which encourages earlier exit. On the other hand, a high value of g_j also lowers the profits from re-entry, which discourages exit. The proof shows that the first effect dominates the second.[11]

While the simple vintage model with Assumption 1 reproduces the ISTC-turnover relationship in Section 2, it does not replicate the entry cost interaction:

Proposition 5 *Under Assumption* 1, *entry costs disproportionately lower entry and exit rates in industries with* low *rates of ISTC.*

When there is no updating, agents must pay the entry cost to adopt a new technology. Entry costs delay adoption: however, they delay adoption mainly for industries with low g_j – which already have low adoption rates – as a further delay in adoption is least costly in such industries. Entry costs increase cross-industry variation in entry and exit rates – contrary to the evidence. We will examine below whether the same is true in the more general model: however, the proposition suggests that the possibility of updating will be essential to matching the ISTC-entry cost interaction seen in the data.

5.2 Entry and exit in the model with updating

Returning to the general model without Assumption 1, the result in Proposition 4 can no longer be proven analytically. However, there are several reasons why the general model might be expected to account for the data even better than the simple model. Two additional channels affect industry rates of entry and exit: the following discussion assumes for simplicity that $\zeta(g_j) = \zeta$.

First, if enterprises may update, then whether or not enterprises exit depends on z. Enterprises will exit (instead of updating) if $z \leq z^*$ where

$$(1 - E) \int V^j(0, z) \psi(z) \, dz = V^j(0, z^* \zeta) . \tag{19}$$

If $\frac{dz^*}{dg} > 0$, then higher rates of ISTC are associated with a larger set of enterprise types exiting instead of updating. The threshold z^* is endogenous and depends on the distribution ψ, so z^* cannot be derived analytically. However, taking the total derivative of (19) with respect to g_j,

$$\frac{dz^*}{dg} = \frac{(1 - E) \int V_g^j(0, z) \psi(z) \, dz - V_g^j(0, z^* \zeta)}{\zeta V_z^j(0, z^* \zeta)} . \tag{20}$$

[11] Industries with a high capital share should also experience more entry and exit, something that is consistent with the results of Audretsch (1991). This is because the rate at which a plant's profitability falls behind the frontier is $\frac{\alpha_k}{1-\alpha_n-\alpha_k} \times g_j$.

It is straightforward to show that $V_z^j(0, z^*\zeta) > 0$, and that V_g^j is negative and larger in magnitude for larger z. Thus, $\frac{dz^*}{dg} > 0$ provided that z^* is "large" relative to the shock values drawn by entrants. This dovetails with the fact that low initial shock values are a natural feature of many models that wish to match the higher exit rates among entrants documented by Dunne, Roberts and Samuelson (1989).

Second, there exists a productivity value z^{**} such that enterprises drawing $z \leq z^{**}$ exit as soon as their shock value is revealed. Value z^{**} is given by

$$(1 - E) \int V^j(0, z)\, \psi(z)\, dz = V^j(0, z^{**}). \tag{21}$$

Clearly $z^{**} = z^*\zeta$ and $\frac{dz^{**}}{dg} = \zeta \frac{dz^*}{dg}$. Hence, depending on the form of ψ, higher rates of ISTC may induce stronger selection among enterprises, so that a larger proportion of the type space exits instead of updating once its technology has become obsolete.

What about the interaction of entry costs and g_j? In the data, the fact that turnover decreases more in industries with high ISTC requires $\frac{d^2 z^*}{dgdE} < 0$. Equation (20) suggests this might hold, as the expression for $\frac{dz^*}{dg}$ is decreasing in E when $\frac{dz^*}{dg} > 0$. However, the derivatives of V^j in equation (20) also depend on E indirectly, so that the condition $\frac{d^2 z^*}{dgdE} < 0$ cannot be proven analytically.

5.3 Calibration

We now calibrate the model to US industry and macroeconomic data, to assess to what extent the model is capable of reproducing the stylized facts presented earlier.

The calibration procedure is as follows. First, along a balanced growth path, several parameters can be determined from aggregate data using the procedure of Kydland and Prescott (1982). Then, parameters that govern the enterprise lifecycle are chosen by calibrating a "typical" industry. Finally, given the values of g_j for the 41 industries presented in Table 2, the aggregate economy can be constructed using reported industry shares of GDP.

The calibrated model is a discrete time approximation to the continuous model presented herein, and is discussed in detail in the working version of the paper. Period length is one year, and $\eta = 1$. Productivity z is drawn from a grid of 100 points, where $z \in (0, 1]$.

Computing industry exit rates requires calibrating the distribution ψ of entrant productivity and the process f that changes productivity thereafter. The distribution ψ is modeled as a log normal distribution truncated at the end points, with mean μ_ψ and standard deviation σ_ψ. Dunne et al (1989) find that enterprises tend to grow faster early in life, suggesting that z_t at a given enterprise may trend upwards over time. Assume that

$$\log z_{t+1} = \xi \log z_t + \epsilon_{t+1}$$

where the disturbances ϵ_{t+1} are normal with mean zero and standard deviation σ_ε, but the distribution is truncated so that $z_t \in (0,1]\ \forall t$.[12]

The adoption cost function $\zeta(g_j) = \bar{\zeta} - \theta g_j$. As we shall see, the sensitivity of adoption costs to ISTC (parameter θ) is important for many of the quantitative results below. As a benchmark we set $\theta = 0$, but consider values of $\theta \in [0, 10]$. When $\theta = 10$, adoption costs in an industry with $g_j = 0.01$ and one with $g_j = 0.08$ differ by a factor of 6.[13] For a given value of θ, the value of $\bar{\zeta}$ is chosen so that $\zeta(g_j)$ equals the benchmark value for the median g_j.

To calibrate the model requires values for μ_ψ, σ_ψ, ξ, σ_ε, ζ, χ, E and ρ. Some of these parameters can be mapped into the model directly from aggregate data:

1. A value of $\alpha_n = 0.63$ lies in the mid-range of estimates of the labor share. As for α_k, the Bureau of Economic Analysis reports that income from equity and proprietorships has averaged 12 percent of GDP since the 1950s. Identifying this with $1 - (\alpha_k + \alpha_n)$ yields $\alpha_k = 0.25$.[14]

2. The rate of time preference ρ is related to the equilibrium return on capital. Greenwood et al (1997) use a value of 0.07. The US NIPA report economic growth of 2.2 percent per year over the post-war period, implying that $\rho = 0.045$.

3. Demand parameters ω_j can be computed from the shares of GDP made up by each of the 41 industries in the data set. I exclude the share of GDP made up for by government services and farming, which averaged about 15 percent over the postwar period.

[12] To see how this is trends upwards, consider that $\log z_{t+1} = \log z_t - (1-\xi)\log z_t + \epsilon_{t+1}$, where ϵ_{t+1} is drawn from a normal distribution, truncated so as to keep $z_{t+1} \leq 1$. The extent to which firms are likely to increase is lower depending on their size. If $\xi < 1$ then firms will be drawn towards $z = 1$, which is the upper bound.

[13] Such large adjustment cost differences are empirically reasonable. For example, Greenwood and Jovanovic (2001) find that investments in information technology (IT) have a rate of return of about 2000 percent, interpreting this as an indicator of unmeasured adoption costs.

[14] Atkeson and Kehoe (2005) estimate that in US manufacturing, 9 percent of output cannot be accounted for as payments to capital nor labor. On the other hand, they also estimate a "span of control" parameter of 15 percent. Thus, depending on the interpretation of $1 - (\alpha_k + \alpha_n)$, this suggests that $\alpha_k \in [0.22, 0.28]$. We will also discuss values in this range.

4. The entry cost E captures both technological factors E^T and institutional factors E^C. Waddell, Ritz, Norton and Wood (1966) report that it takes about a year to set up a enterprise in most industries, and one year is also the time-to-build assumed in Kydland and Prescott (1982) and Campbell (1998). This points to a technological delay $d = 1$, so that $E^T = 1 - e^{-\rho}$. As for institutional entry costs, Djankov et al (2002) report that the formal cost of entry in the United States as a percentage of GDP per capita is negligible. Hence, in the benchmark economy, bureaucratic costs $E^C = 0$.

To study the interaction of entry costs and ISTC requires selecting a range of values of E^C, the formal cost of entry in terms of expected profits, for the countries in the study. According to Djankov et al (2002), the cost of entry ranges between 5.6 percent and 81 percent of GDP per capita. This corresponds to $E^C \in [0.003, 0.046]$.

Param.	α_k	α_n	μ_ψ	σ_ψ	ξ	σ_ε	χ	ζ	ρ	E^T	E^C	θ
Value	0.25	0.63	0.084	1.56	0.75	0.2	0.089	0.69	0.045	0.044	0	0

Table 7 – Parameters used in the benchmark calibration.

Detailed data on industry dynamics are mostly available only for the manufacturing sector. Hence, the remaining parameters are chosen so that a "typical" manufacturing industry in the model economy behaves as the manufacturing sector does overall. I do so by considering an industry in which g_j takes the median value for the manufacturing sector (the median and the mean are both about 0.04), and choosing the remaining parameters to match several features of the lifecycle of manufacturing enterprises in the US. This approach is made possible by the fact that, in equilibrium, the optimal decision rules in each industry do not depend on the level of prices or wages. The six remaining parameters are μ_ψ, σ_ψ, ζ, ξ, σ_ε, and χ, and the six statistics to be matched are:

1. the average exit rate, reported in Dunne et al (1989).[15]

2. the exit rate among the young (aged 0-5 years), reported in Dunne et al (1989).

3. the average growth rate – from David S. Evans (1987a).

[15] Dunne et al (1989) report the exit rate based on the Census of Manufactures, which is conducted every 5 years. This rate is 0.36. Since the model is annual, the calibrated annual exit rate will exceed $1 - (1 - 0.36)^{0.2}$, as many entrants would exit without ever appearing in the Census. The same applies to the exit rate among the young, which is 0.40. These data are for establishments, nor enterprises, but similarly detailed data for enterprises was not available.

4. the average growth rate among the young – from Evans (1987a).
5. the log standard deviation of growth rates – from Evans (1987b).
6. the "lumpiness" of investment. Doms and Dunne (1998) report that the share of establishments experiencing an increase in the capital stock of 30 percent or higher is 6 percent.[16] This requires the model to fit not just the mean and standard deviation of growth rates but also the skewness of the growth rate distribution. Lumpiness in the model is related to the frequency of updating by incumbents.

Table 7 reports the resulting parameters, and Table 8 reports summary model statistics. The matches are generally quite tight. Interestingly, average size among entrants is only 2/3 of the average size among all enterprises. This is in spite of the fact that entrants adopt the frontier technology, as in a canonical vintage capital model.

In the model, the exogenous annual exit rate is $\chi = 0.089$. The annual exit rate is 12.6 percent. Thus, annual turnover in the median industry of about 4 percent is endogenous and due to ISTC, the remainder being attributed to factors that are not modeled explicitly.

Statistic	US data	Model
5-year exit rate (young)	0.40	0.40
5-year exit rate	0.36	0.36
Growth rate (young)	0.06	0.06
Growth rate	0.02	0.02
Growth rate, log s.d.	-2	-2
enterprises with investment lumps	0.06	0.05

Table 8 – Model statistics used in calibration. The column "Model" report the behavior of the median manufacturing industry, which is Manufacturing Not Elsewhere Classified.

[16] The published version of Doms and Dunne (1998) reports a different number, but entrants and exiters are excluded from that sample. 6 percent is the value in the panel that includes entry and exit. This is also the median industry value in Compustat.

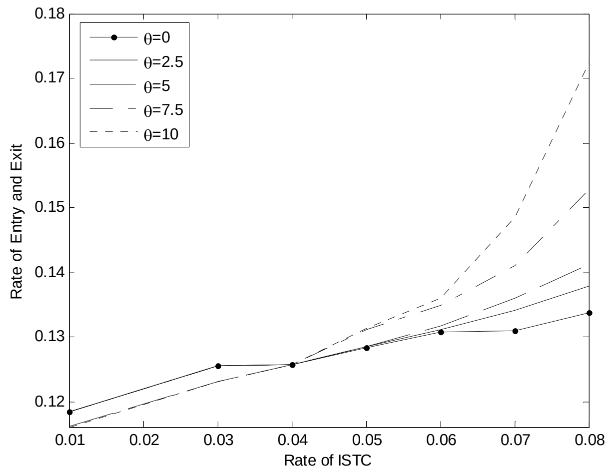

Figure 3: Industry rates of entry and exit, depending on the industry rate of ISTC and on the relationship between ISTC and adoption costs (θ). Rates of entry and exit are positively related to ISTC, and the relationship is stronger for larger values of θ.

5.4 Results

5.4.1 ISTC and Turnover

In the data, rates of ISTC range from 1 to 8 percent across industries. In the model, when $\theta = 0$, this generates a range of annual entry rates from 11.8 to 13.4 percent per year. A higher rate of ISTC increases industry turnover even though incumbents have the option to update instead of exiting. In the data, entry rates range from 8.7 to 17.1 percent, so the benchmark model covers about one fifth of the range.[17]

Larger values of θ are be associated with a wider divergence of cross-industry turnover rates generated by g_j, as $\theta > 0$ implies that adoption by incumbents becomes costlier for higher g_j. See Figure 3. A way to get a sense of the magnitude of this relationship is to regress ISTC for the 41 industries on their turnover rates in the model economy – see Table 9. These coefficients are always positive. In the case of turnover, they range from about a third of the coefficient in the data when $\theta = 0$ to three quarters when $\theta = 5$ and 115 percent when $\theta = 10$.

Figure 4 depicts the impact of parameter changes on the optimal decision rules.

[17] When the model is re-calibrated for values of $\alpha_k \in [0.22, 0.28]$, the model covers $12-30$ percent of the range when $\theta = 0$.

Consider the north west cell of Figure 4, which corresponds to $g_j = 0.01$ and $\theta = 0$. Firms vary by productivity z_t and age, measured in years. Firms are born somewhere on the vertical axis, depending on their initial draw of z_t. For example, a newborn firm with $z_t = 0.5$ is at the center of the vertical axis. As it ages it moves towards the right, horizontally if it maintains its value of z_t, or stepping up or down whenever it receives a positive or negative productivity shock. At some point as it moves towards the right it may touch the boundary of the area labelled "Update", in which case it returns to the vertical axis at a point ζz_t. Alternatively, it might touch the boundary of the region labeled "Exit", in which case the firm closes. If the firm was born with a low value of z_t (about 0.2), then the firm exits immediately.

	ISTC	coefficient		
	Data	Model, $\theta = 0$	Model, $\theta = 5$	Model, $\theta = 10$
Turnover	1.24*** (0.326)	0.41*** (0.000)	0.91*** (0.000)	1.43*** (0.000)
Entry	0.81*** (0.240)	0.21*** (0.000)	0.45*** (0.000)	0.72*** (0.000)
Exit	0.43*** (0.122)	0.21*** (0.000)	0.45*** (0.000)	0.72*** (0.000)

Table 9 – Coefficients of a regression of turnover measures on ISTC. Standard errors are in parentheses. The first column corresponds to the data and is drawn from Table 3. The remaining columns represent the model economy. Standard errors in the model economy are negligible by construction as ISTC is the only source of cross-industry variation.

When $\theta = 0$, the size of the "Exit" region plays very little role in the link between turnover and ISTC. Observe the leftmost column of Figure 4: the line separating regions of the type space corresponding to exit and updating does not vary with the value of g_j. In fact, under 1 percent of enterprises lie between the value of z^* corresponding to $g_j = 0.04$ and the values of z^* corresponding to other choices of $g_j \in [0.01, 0.08]$. On the other hand, the size of the "Update" area varies a lot with g_j. Thus, when θ is low, z is the main determinant of *which* enterprises exit, whereas g_j governs the *timing* of exit and of updating.

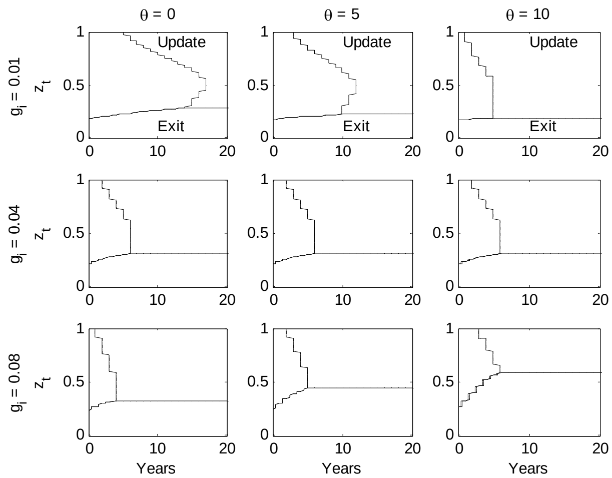

Figure 4: Decision rules for different rates of ISTC g_j and different values of the adoption cost parameter θ. The exit threshold z^* is visibly more sensitive to changes in g_j when θ is high, whereas the date of updating or exit T^* is more sensitive to g_j when θ is low.

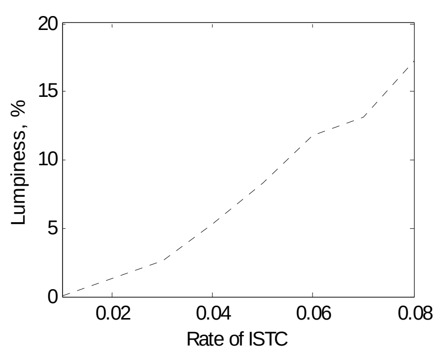

Figure 5: Investment lumpiness and ISTC in the model economy, $\theta = 0$. Lumpiness is the proportion of firms in the model economy that display an investment "spike" each year, in an industry with a given rate of ISTC. This share is increasing in the rate of ISTC, as in the data.

For high values of θ, however, the set of enterprises that exits is much more sensitive to g_j, as a change in g_j also corresponds to an increase in the eventual costs of continuation. For instance, when $\theta = 5$, 9 percent of enterprises lie between the value of z^* corresponding to $g_j = 0.04$ and the value of z^* corresponding to $g_j = 0.08$. When $\theta = 10$ this proportion rises to 33 percent.

5.4.2 ISTC and investment lumpiness

Not only does a higher rate of ISTC lead to earlier exit in the model: among enterprises that do not close, it also leads to earlier updating. This too has a significant impact on lifecycle dynamics: although it does not lead to exit, it leads to a "spike" in investment at the enterprise level. As in Doms and Dunne (1998), a "spike" is defined as a year in which investment expenditures exceed 30 percent of the enterprise capital stock. In the model, such spikes may occur because of large changes in z_t or because of updating but, in the calibrated economy, all the spikes in the benchmark economy are due to updating.

Figure 5 shows that the frequency of investment spikes is positively related to the rate of ISTC. In the model economy a 1 percent increase in the rate of ISTC leads to a 2.5 percent increase in the prevalence of investment spikes,[18] roughly half of the value in Section 2.

5.4.3 ISTC and Entry costs

Section 2 reports that entry costs reduce turnover in industries in which ISTC is rapid, compared to industries in which it is sluggish. Using the entry cost measures of Djankov et al (2002) and the industry ISTC measures constructed in this paper, I used the model to compute entry and exit rates for each of the 41 industries in the 18 countries in Eurostat. Then, I ran the same differences-in-differences regression on the artificial data. As in the "true" data, the interaction coefficients are all negative. Once more, matching the magnitude of the empirical coefficients turns out to require a large value of θ – see Table 10. High θ increases the share of firms that exit instead of updating, so that an increase in entry costs has an impact on the behavior of a larger share of entrepreneurs in any given industry.

[18] Variation in θ does not significantly change this coefficient.

Specification	Turnover measure	Interaction coefficient
Baseline spec., with Eurostat data.	Turnover Entry Exit	-0.68 -0.31 -0.37
Baseline spec., with model pseudo-data. $\theta = 0$.	Turnover Entry Exit	-0.07 -0.03 -0.03
Baseline spec., with model pseudo-data. $\theta = 10$.	Turnover Entry Exit	-0.50 -0.25 -0.25

Table 10 – Artificial entry and exit data generated with the model, regressed on an interaction of ISTC and entry costs. The results are compared with the same regression using Eurostat data (Table 5). The qualitative results are similar, but the model requires a large effect of technological change on adjustment costs θ to generate interaction coefficients of similar magnitude to the data. For the artificial data the R^2 is almost 100 percent by construction, as ISTC and entry costs are the only sources of variation in the artificial data.

6 Concluding Remarks

This paper is motivated by two observations. First, cross-industry differences in entry and exit rates remain largely unexplained by measures of industry profitability or entry barriers. Second, vintage capital models in general have a strong prediction: if technical progress is embodied in the enterprise, then rates of technical progress should be positively related to rates of entry and exit. The paper concentrates upon the case of technical progress in the production of the capital goods used by each industry, finding support for this basic prediction of vintage models. Moreover, the model economy accounts for the relationship between turnover and the rate ISTC, provided there is a positive link between this rate and adoption costs. The data and the model both point to an interaction between the costs of entry and the diffusion of new technologies through entry and exit. However, a full assessment of the welfare implications of policy might require endogenizing the rate of ISTC, for example allowing firms to substitute between capital goods with different rates of ISTC. This is left for future work.

A Appendix

A.1 Data

An "enterprise" is defined as a legal entity, identified from the business register in each country: registering is required to legally produce and sell goods and services, and to pay taxes. If an enterprise ceases operations, by law it must notify the business register within a few months.[19] This is similar to the definition of a "firm" according to the United States Census Bureau.

Mergers and changes of legal status are distinguished from "true" entries and exits. For example, changes of legal status can be identified by the fact that the number of enterprises at the beginning or end of the event does not change, whereas mergers affect some number $n > 1$ of enterprises leaving one enterprise at the end: this changes the number of enterprises but is not counted as entry nor exit.[20]

The data follow Council Regulation (EC) 58/97, which resolved to "establish a common framework for the collection, compilation, transmission and evaluation of Community statistics on the structure, activity, competitiveness and performance of businesses in the Community." However, participation was not mandatory. Hence, the paper does not report results for France and Germany. Germany did not participate and, while France did participate, it did not distribute the data through Eurostat at the time of writing.

In this paper, industry classifications are based on the North American Industry Classification System (NAICS) used by the BEA capital flow tables.[21] The 61 non-farm industries reported in the capital flow tables are aggregated to 41 industries, to yield a coarser classification system that allows concordance with the Eurostat

[19] Individual country registration rules may be found at:
http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/sbs_base_an2.htm

[20] Further details of the identification strategy are available from Eurostat:
http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-07-010/EN/KS-RA-07-010-EN.PDF

[21] See http://www.bea.gov/national/FA2004/Details/Index.html.

data. The aggregation process is generally straightforward: for example, Healthcare aggregates Ambulatory health care services, Hospitals, Nursing and residential care facilities, and Social assistance.[22]

Eurostat uses the Nomenclature générale des activités économiques dans les Communautés européennes (NACE) classification system, Revision 1.1. The Bank of Canada kindly provides a detailed concordance table for the NAICS and NACE Rev. 1.1 systems.[23] Two industries from the BEA's list – "Management of companies and enterprises" and "Administrative and support services" – were difficult to map into Eurostat, and were left out of the analysis.

A.2 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 for any industries i and j

$$\frac{r_i(x,t)}{r_j(x',t)} = \frac{x'}{x} \tag{22}$$

The return to capital must be equal and, since the cost of capital 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 rental rate depends only on the level of x, not on the industry. Thus, in particular,

$$r_j(x,t) = \frac{\bar{x}_{jt}}{x} r_j(\bar{x}_{jt}, t) \tag{23}$$

or, for any technology $\tau \leq t$, from (22), $r_j(x,t) = r_j(\bar{x}_{j0}, t)\, e^{-g_j \tau}$, where $r_j(\bar{x}_{j0}, t)$ is the interest rate on capital of vintage zero and τ is the date at which technology x was the frontier for industry j, so $x = \bar{x}_{jt} e^{-g_j \tau}$. Thus, capital is relatively more

[22] The resulting industries are Oil and gas extraction; Other mining; Utilities; Construction; Wood products; Nonmetal products; Primary and fabricated metal products; General Machinery; Computers and electronic prod.; Electrical machinery; Transport Equip.; Manuf n.e.c.; Food products; Textiles; Leather; Paper, printing, software; Petroleum and coal products; Chemicals; Plastics and Rubber; Wholesale Trade; Retail Trade; Air transport; Water transport; Land transport; Transport support; Broadcasting; Information and data processing; Finance (not insurance; trusts); Insurance; trusts; Real estate; Rental services; Legal services; Systems design; Technical Services; Waste; disposal; Education; Healthcare; Arts, sports, amusement; Hotels; Restaurants; Other services.

[23] See http://www.statcan.ca/english/Subjects/Standard/concordances/naics2002-to-nacerev1-1.htm.

expensive to rent for enterprises with older technology. Note that we can rewrite the enterprise's problem in terms of τ instead of in terms of x. In addition, let $\tilde{p}_j(x,t) = \int_t^\infty e^{-(\rho+\delta)(t-s)} r_j(x,s)\,ds$ be the discounted value of rentals of a unit of capital – where a constant discount rate is assumed as along a BGP. Differentiating with respect to t, the marginal product of capital is

$$r_j(x,t) = (\rho+\delta)\,\tilde{p}_j(x,t) - \frac{d\tilde{p}_j(x,t)}{dt}$$

Optimal investment requires that $\tilde{p}_j(x,t) = x^{-1}$, so that $\frac{d\tilde{p}_j(x,t)}{dt} = 0$. Substituting, we have that $r_j(x,t) = (\rho+\delta)\,x^{-1}$. ■

Proof of Lemma 1 and Proposition 3. Notice that production is a static decision. Solving for optimal labor and capital input, (7) becomes

$$\pi(z_t,x_t) = (p_{jt}A_{jt}z_t)^{\frac{1}{1-\alpha_n-\alpha_k}} \frac{C^{\frac{1}{1-\alpha}}}{r_j(x,t)^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}}} \left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right] \tag{24}$$

where $\alpha = \frac{\alpha_k}{1-\alpha_n}$, $C = \left(\frac{\alpha_n^{\frac{\alpha_n}{1-\alpha_n}} - \alpha_n^{\frac{1}{1-\alpha_n}}}{w_t^{\frac{\alpha_n}{1-\alpha_n}}}\right)$. Now, given that $r_j(x,t) = (\rho+\delta)\,\bar{x}_{j0}e^{-g_j\tau}$, this becomes

$$\pi(z_t,x_t) = (p_{jt}A_{jt}z_t)^{\frac{1}{1-\alpha_n-\alpha_k}} \frac{C^{\frac{1}{1-\alpha}}}{\left((\rho+\delta)\,\bar{x}_{j0}e^{-g_j\tau}\right)^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}}} \left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right] \tag{25}$$

Suppose labor is the numeraire. Then the value of an entrant must be constant over time, so that, if ϕ_j is the growth rate of p_{jt} then

$$\phi_j = -g_j\alpha_k - \kappa_j,\ p_{jt} = p_{j0}e^{-(\alpha_k g_j+\kappa_j)t} \tag{26}$$

Then, if $B_j = C^{\frac{1}{1-\alpha}}\left[\alpha^{\frac{\alpha_k}{1-\alpha_n-\alpha_k}} - \alpha^{\frac{1-\alpha_n}{1-\alpha_n-\alpha_k}}\right](p_{j0}A_{j0})^{\frac{1}{1-\alpha_n-\alpha_k}}\left[(\rho+\delta)\,\bar{x}_{j0}\right]^{\frac{-\alpha_k}{1-\alpha_n-\alpha_k}}$, and $a = t-\tau$ is the age of the enterprise's technology (with respect to the frontier), we have that $\pi(z_t,a) = B_j z_t^{\frac{1}{1-\alpha_n-\alpha_k}} e^{-\frac{\alpha_k g_j}{1-\alpha_n-\alpha_k}a}$ or, setting $\gamma_j = \frac{\alpha_k g_j}{1-\alpha_n-\alpha_k}$ and $s_t = z_t^{\frac{1}{1-\alpha_n-\alpha_k}}$, $\pi(z_t,a) = B_j s_t e^{-\gamma_j a}$. Thus, here, enterprise profits depend only on z and on the distance from the industry frontier. With this under our belts, we can write the enterprise's problem recursively, impose condition (8) for industry j, and divide through by B_j to obtain value function (17), which does not depend on the date, only on industry parameters. ■

Proof of Proposition 1. Let μ_j^* be the measure of enterprises in industry j in a steady state. Suppose μ_j^* exists and is unique. Set the numeraire $w_t = 1$. As shown by Ngai and Samaniego (2007) the consumer's solution implies that across goods i, j, $\frac{p_i c_i}{p_j c_j} = \frac{\omega_i}{\omega_j}$, so $p_j c_j = \omega_j s_c$ where s_c is total spending on consumption and the demand for each good j is $c_j = s_c \frac{\omega_j}{p_j}$. Hence, whatever spending on consumption might be, the share of each good is fixed. Define $p_c \equiv \frac{s_c}{c} = \prod_{j=1}^{J} p_j^{\omega_j}$. Now in a BGP it must be that their income is growing. So, for constant labor, we need w_t/p to be constant over time, so $g_p = g_w$. Setting $w = 1$ to be the numeraire, then $g_p = 1$. Recall that p_{jt} drops over time at rate $-\phi_j$. Given a constant mass of enterprises μ_j^*, real output grows at rate $-\phi_j$, so this equation holds provided $c_{j0} = s_c \frac{\omega_j}{p_{j0}}$. Now p_{j0} is given by the entry condition (8), so shares of consumption are given and

$$p_c = \prod_{j=1}^{J} p_j^{\omega_j} = \left[\prod_{j=1}^{J} p_{j0}^{\omega_j} \right] e^{\sum_j \phi_j \omega_j t}. \tag{27}$$

Real consumption grows at a constant rate $\sum_j \phi_j \omega_j$, and the share of each type of good is constant and given by p_{j0}. Notice that the output of each enterprise is not linear in p_{j0} (it is strictly convex) so that for any p_{j0} there is a unique mass of enterprises in that industry that can satisfy demand for a given value of consumption spending s_c. (which pins down the entry rates ε_j). Conversely, given a total mass of enterprises s_c and the distribution of enterprises 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 enterprises is constant. Income is linear in the total number of enterprises. Hence, the number of enterprises that clears the labor market is the equilibrium number, which leads to equilibrium values of income, spending, and all other variables as above. Such a number exists because labor supply is inelastic – see Hopenhayn and Rogerson (1993).

It remains to verify that, given constant decision rules T, X and Υ, and given a constant volume of entrants ε_j, there exists a unique measure of agents μ_j^* that is invariant over time for each industry. This verification is notationally cumbersome without being informative and is available from the author upon request. ■

Proof of Proposition 4. The enterprise's problem can be written:

$$\begin{aligned} V^j(a,s) &= e^{(\rho+\chi)a} \max_T \left\{ \int_a^T e^{-(\rho+\chi)a} \left[s e^{-\gamma_j t} + \chi U^j \right] dt \right. \\ & \left. e^{-(\rho+\chi)T} U^j \right\}, \; U^j = V^j(0,s)(1-E). \end{aligned} \tag{28}$$

where the constant B_j has been divided out as it enters V^j (and hence U^j) multiplicatively. Although this is a continuous time problem, it can be approached using discrete time recursive methods. Dividing through by s, the first order conditions for T given U^j require $e^{-\gamma_j T} = \rho U^j$, so that T is decreasing in U^j. Suppose U^j is the payoff assuming that $\gamma_j = 0$. That is strictly larger than $V^j(0,s)(1-E)$, so the true solution (if it exists) necessarily has T larger than T^{**}, which is the solution to that problem.

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

$$\begin{aligned} BV^j(0,s) &= \max_{T\in[T^{**},\infty)} \left\{ \int_0^T e^{-(\rho+\chi)a} e^{-\gamma_j t} dt + \chi U^j \right. \\ & \qquad \left. e^{-(\rho+\chi)T} U^j \right\},\ U^j = V^j(0,s)(1-E) \end{aligned} \tag{29}$$

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 γ satisfies $-\gamma T_\gamma - T = \frac{U_g^j}{U^j}$. Solving for U^j,

$$U^j = \frac{\left[1 - e^{-\left(\rho+\gamma_j\right)T}\right]}{\left(\rho+\gamma_j\right)\left[\frac{1}{1-E} - e^{-\rho T}\right]} \tag{30}$$

and

$$U_\gamma^j = \frac{-Te^{-\left(\rho+\gamma_j\right)T}\left(\rho+\gamma_j\right) - \left[1 - e^{-\left(\rho+\gamma_j\right)T}\right]}{\left(\rho+\gamma_j\right)^2\left[\frac{1}{1-E} - e^{-\rho T}\right]}. \tag{31}$$

Thus $T_\gamma < 0$ if and only if

$$T > \frac{Te^{-\left(\rho+\gamma_j\right)T}\left(\rho+\gamma_j\right) + \left[1 - e^{-\left(\rho+\gamma_j\right)T}\right]}{\left(\rho+\gamma_j\right)\left[1 - e^{-\left(\rho+\gamma_j\right)T}\right]} \tag{32}$$

As $g \to 0$, $T \to \infty$ so this becomes $1 > \lim_{T\to\infty} \frac{e^{-\left(\rho+\gamma_j\right)T}\rho + \frac{1}{T}}{\rho} = 0$, so the condition is satisfied. More generally, the inequality implies

$$\left(\rho+\gamma_j\right)\left[1 - 2e^{-\left(\rho+\gamma_j\right)T}\right]T > \left[1 - e^{-\left(\rho+\gamma_j\right)T}\right]. \tag{33}$$

Define $\hat{T}$ using $\left(\rho+\gamma_j\right)\left[1 - 2e^{-\left(\rho+\gamma_j\right)\tau}\right]\hat{T} = \left[1 - e^{-\left(\rho+\gamma_j\right)\tau}\right]$. If there exists γ such that $T_\gamma > 0$ then there must exist a γ 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^*. Let $\Delta > 0$. The exit rate as $\Delta \to 0$ is $\lim_{\Delta \to +0} \tilde{\xi}(\Delta)/\Delta + \chi$, where the share of firms exiting endogenously is $\tilde{\xi}(\Delta) = \frac{\int_{T^*-\Delta}^{T^*} e^{-\chi t} dt}{\int_0^{T^*} e^{-\chi t} dt} = \frac{\int_{T^*-\Delta}^{T^*} e^{-\chi t} dt}{1-e^{-\chi T^*}}$, so that $\Omega \equiv \lim_{\Delta \to +0} \frac{\tilde{\xi}(\Delta)}{\Delta} = \frac{e^{-\chi T^*}}{1-e^{-\chi T^*}}$. ■

Proof of Proposition 5. Deriving the expression for T^* with respect to E and then g yields $-T_E^* - \gamma_j T_{Eg}^* = \frac{U_{Eg}^j U^j - U_E^j U_g^j}{(U^j)^2}$. Expanding using the expression for U yields

$$-\gamma_j T_{Eg}^* = \frac{T_g \rho e^{-\rho T}}{(1-E)\left[\frac{1}{1-E} - e^{-\rho T}\right]^2} + T_E^*$$

If g is very small,

$$T_{gE}^* \approx -U_E^j \frac{T^*}{\gamma_j^2 U_g^j} < 0$$

and as $g \to \infty$ the cross derivative goes to zero. Algebraic manipulation shows that T_{Eg}^* is monotonic in g (i.e. $T_{Egg}^* > 0$), so that $T_{gE}^* < 0$ always. The result follows as the signs of T^* and its derivatives are the opposite of the signs of entry/exit Ω and its derivatives:

$$\begin{aligned} \Omega &\equiv \frac{e^{-\chi T^*}}{1-e^{-\chi T^*}}, \Omega_g = -T_g \frac{\chi \Omega}{1-e^{-\chi T^*}}, \Omega_E = -T_E \frac{\chi \Xi}{1-e^{-\chi T^*}} \\ \Omega_{Eg} &= -T_{Eg} \frac{\chi \Omega}{1-e^{-\chi T^*}} + T_g T_E \frac{\chi^2 \Omega}{(1-e^{-\chi T^*})^2}\left[1+e^{-\chi T^*}\right] > 0. \end{aligned}$$

■

B Bibliography

Atkeson, Andrew and Patrick J. Kehoe. 2005. Modeling and Measuring Organization Capital. Journal of Political Economy 113(5), 1026-1053.

Audretsch, David B. 1991. New-enterprise Survival and the Technological Regime. Review of Economics and Statistics 73(3), 441-450.

Bessen, James. Technology Adoption Costs and Productivity Growth: The Transition to Information Technology. Review of Economic Dynamics, 2002, 5 (2), 443-69.

Brandt, Nicola. 2004. Business Dynamics in Europe. OECD Science, Technology and Industry Working Paper 2004/1.

Campbell, Jeffrey R. 1998. Entry, Exit, Embodied Technology, and Business Cycles. Review of Economic Dynamics 1, 371-408.

Cummins, Jason G. and Giovanni L. Violante. 2002. Equipment-Embodied Technical Change in the US (1947-2000): Measurement and Macroeconomic Consequences. Review of Economic Dynamics 5, 243-284.

Djankov, Simeon, Rafael La Porta, Florencio Lopez-de-Silanes and Andrei Shleifer. 2002. The Regulation of Entry. Quarterly Journal of Economics 117, 1-37.

Doms, Mark and Timothy Dunne. 1998. Capital Adjustment Patterns in Manufacturing Plants. Review of Economic Dynamics 1(2), 409-429.

Dunne, Timothy, Mark J. Roberts and Larry Samuelson. 1988. Patterns of enterprise Entry and Exit in U.S. Manufacturing Industries. RAND Journal of Economics 19(4), 495-515.

Dunne, Timothy, Mark J. Roberts and Larry Samuelson. 1989. Larry. The Growth and Failure of U. S. Manufacturing Plants. Quarterly Journal of Economics 104(4), 671-698.

Evans, David S, 1987a. Tests of Alternative Theories of enterprise Growth. Journal of Political Economy 95(4), 657-74.

Evans, David S., 1987b. The Relationship Between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries. Journal of Industrial Economics 35, 567-581.

Geroski, Paul A. 1989. Entry, Innovation and Productivity Growth. The Review of Economics and Statistics, 71 (4), 572-578.

Geroski, Paul A. 1995. What do we know about entry? International Journal of Industrial Economics 13, 421-440.

Greenwood, Jeremy, Zvi Hercowitz and Per Krusell. 1997. Long-run Implications of Investment-Specific Technological Change. American Economic Review 87, 342-362.

Greenwood, Jeremy and Boyan Jovanovic. 2001. Accounting for Growth. In Charles R. Hulten, Edwin R. Dean, and Michael J. Harper, eds., New Developments in Productivity Analysis, NBER Studies in Income and Wealth, Vol. 63. Chicago and London: University of Chicago Press, 179-222.

Greenwood, Jeremy and Mehmet Yorukoglu. 1997. 1974. Carnegie-Rochester Conference Series on Public Policy 46 (0), 49-95.

Hopenhayn, Hugo A. and Richard Rogerson. 1993. Job Turnover and Policy Evaluation: A General Equilibrium Analysis. Journal of Political Economy 101(5), 915-938.

Jovanovic, Boyan and Yaw Nyarko. 1996. Learning by Doing and the Choice of Technology. Econometrica 64(6), 1299-1310.

Jovanovic, Boyan and Chung-yi Tse. 2006. Creative Destruction in Industries. NBER Working Paper No. W12520.

Khan, Aubhik and Julia Thomas. 2008. Idiosyncratic shocks and the role of nonconvexities in plant and aggregate investment dynamics. Econometrica 76(2), pages 395-436.

Klenow, Peter. 1998. Learning Curves and the Cyclical Behavior of Manufacturing Industries. Review of Economic Dynamics 1(2), 531-550.

Kydland, Finn E. and Edward C. Prescott. 1982. Time to Build and Aggregate Fluctuations. Econometrica 50, 1345-70.

Lazear, Edward. 2005. Entrepreneurship. Journal of Labor Economics 23(4), 649-80.

McAfee, R. Preston, Hugo M. Mialon and Michael A. Williams. 2004. What Is a Barrier to Entry? American Economic Review 94 (2), 461-465.

Mueller, Dennis C and John E. Tilton. 1969. Research and Development Costs as a Barrier to Entry. Canadian Journal of Economics 2(4), 570-579.

Ngai, L. Rachel and Roberto M. Samaniego. 2007. On the Long Run Determinants of Industry TFP Growth Rates. CEPR Discussion Paper DP 6408

Rajan, Raghuram G. and Luigi Zingales. 1998. Financial Dependence and Growth. American Economic Review 88(3), 559-586.

Samaniego, Roberto. 2008. Can Technical Change Exacerbate the Effects of Labor Market Sclerosis? Journal of Economic Dynamics and Control 32(2), 497-528.

Schumpeter, Joseph Alois. 1934. The Theory of Economic Development. Translator: Redvers Opie. Cambridge, MA. Harvard University Press.

Waddell, Robert M., Philip M. Ritz, John D. Norton and Marshall K. Wood. 1966. Capacity Expansion Planning Factors. National Planning Association, Washington, D.C.

World Bank. 2006. Doing Business in 2007: How to Reform. Washington: World Bank.