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Entry, Exit, Technology, and Business Cycles

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Abstract

In the modern U.S. economy, plant exit leads plant entry, entry is moderately procyclical, and exit is countercyclical and has a strong leading relationship with both output and total factor productivity growth. The association of entry and exit with aggregate productivity growth suggests that their fluctuations have a technological origin. In a model economy where plants embody technology, the exit of weak incumbent plants accelerates following an improvement in the leading edge technology. Later, when plants embodying the improvement begin operation, aggregate output and productivity rise. A version of the model mimics the cyclical behavior of entry and exit, suggesting the importance of shocks to the rate of embodied technological change for economic fluctuations.

JEL Classification: L16

1 Introduction

The volume of plant turnover in the U.S. manufacturing sector is enormous. Dunne, Roberts, and Samuelson (1988; 1989a; 1989b) showed that nearly

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40% of plants operating during a given census year no longer exist 5 years later. Entering and exiting plants account for approximately 15% of manufacturing employment. These exit rates tend to be higher across periods when manufacturing employment contracts. With comparable quarterly observations, Davis and Haltiwanger (1990; 1992) document gross employment flows between plants of comparably large magnitude. Furthermore, they show that job reallocation, job growth at expanding plants plus job destruction at contracting plants, is strongly countercyclical. The impact of entry and exit on productivity is also striking. In selected two digit manufacturing industries, both Oley and Pakes (1990) and Bartelsman and Dhrymes (1992) find that exogenous productivity growth at existing plants is trivial. Most observed aggregate productivity growth comes from shifting resources from less to more productive plants.

The volume, timing, and long run impact of entry and exit imply that their study could yield useful insights into macroeconomic fluctuations. The paper's next section contains an empirical study of entry and exit in the U.S. manufacturing sector using Davis and Haltiwanger's (1990; 1992) job creation and destruction data. Both entry and exit exhibit significant cyclical fluctuations. The entry rate, measured by the share of employment at entering plants, is moderately procyclical and is positively correlated with total factor productivity growth. The exit rate is moderately countercyclical, and it has strong leading relationships with entry, output growth, and t.f.p. growth.

The view that fluctuations in entry and exit are primarily driven by shocks to technological opportunities could rationalize the relationship between entry, exit, productivity, and output. The remainder of the paper constructs a model economy which embodies this hypothesis, parameterizes a version of the model, and compares its features to those of the U.S. economy. The model augments King, Plosser, and Rebelo's (1988a; 1988b) general equilibrium business cycle scheme with a selection model of entry and exit resembling Hopenhayn's (1992a; 1992b). The model's theoretical antecedents come from the vintage capital literature. As in the models of Solow (1960; 1962b; 1962a), Greenwood, Hercowitz, and Krusell (1992), and Cooley, Greenwood, and Yorukoglu (1993), only new capital goods incorporate the most recent product innovations. Unlike in these models, technology is fixed for a plant's lifetime, so new innovations must be implemented by entrants. As in the model economy of Greenwood, Hercowitz, and Huffman (1988), shocks to the leading edge technology provide all of the economy's aggregate uncertainty.

An innovation in the leading edge technology accelerates the replacement of old and unproductive plants with new entrants. Output and productivity growth both follow the surge in exit when the new entrants begin production. This chain of events can replicate the observed positive correlations between the exit rate, output growth, and productivity growth.

Dunne, Roberts, and Samuelson (1988) documented the considerable ongoing idiosyncratic uncertainty plants in the U.S. economy face. The character of the exit rate's response to technological improvements crucially depends on incorporating this microeconomic fact. As Dixit and Pindyck (1994) explain, the value of an established plant comes from two assets, the claim on its future dividends and the option to close it. Idiosyncratic uncertainty gives the second asset value. Were it not for the possibility that their fortunes might improve, the economy's marginal plants would have already exited. An improvement in the leading edge technology hastens their exit by *reducing* their chances of experiencing sufficient productivity improvements relative to their competitors.

The model's quantitative assessment requires the computation of its competitive equilibrium. Persistent heterogeneity among the plants implies that the model's state variable is a function rather than a scaler. Accordingly, computation of the model's equilibrium requires an extension of standard dynamic solution techniques. A set of Euler equations and a transversality condition characterize the model's competitive equilibrium. As in the solution method of King, Plosser, and Rebelo (1987) log-linear expansions around a nonstochastic steady state growth path approximate the equations. The model's functional state space implies that they are non-trivial functional equations. Approximation with quadrature methods produces a linear dynamical system with a large but finite dimensional state space. The analysis of the approximate system can apply standard methods, such as those of Blanchard and Kahn (1980) and King, Plosser, and Rebelo (1987).

The model's empirical application asks whether the process of technology implementation can rationalize the empirical associations between plant entry, plant exit, output, and productivity. Using parameter values which match long run features of the model and U.S. economies, a comparison of their second moments answers it in the affirmative. In the model economy, entry covaries positively with output and productivity growth. All three variables follow exit, which is countercyclical.

2 Entry, Exit, and Business Cycles

To produce the Annual Survey of Manufacturers, the U.S. Department of Census compiles a plant level data set covering the population of large plants and a probability sample of small plants in the manufacturing sector[1]. With quarterly employment observations from the ASM panel data set, Davis and Haltiwanger(1990; 1992) and Davis, Haltiwanger, and Schuh (1995) compiled aggregate time series for job creation and destruction, total employment expansion at growing plants and total employment contraction at shrinking plants. Dividing these measurements by total manufacturing employment yields job creation and destruction rates.

Davis and Haltiwanger(1990; 1992) consider two types of job creation, that which occurs at plants which were previously active, and that which occurs at entering plants. Similarly, they divide job destruction into that at plants which remain in production and that at plants which close down. The job creation rate at entering plants, employment at all entering plants divided by total employment, forms an employment weighted entry rate. The job destruction rate at exiting plants, in a like fashion, forms an employment weighted job destruction rate. Davis, Haltiwanger, and Schuh(1995) compiled the exit rate for different plant age categories. Dunne, Roberts, and Samuelson(1989a) showed that the hazard rate for plant exit declines with plant age, so the exit rate for young plants, those less than five quarters old, is also included in the empirical analysis below[2].

Figure 1 begins this study of entry and exit's cyclical behavior by plotting the two series over their sample. The observations begin in the second quarter of 1972 and end in the last quarter of 1988. Because the scale of exit by young plants is so much larger than that for all plants, figure 2 plots this series separately. The most notable feature of entry and exit is their volatility. The entry rate jumped from around 0.2% in the recession of 1975 to its peak of 1.6% in 1976. The exit rate experienced a similar dramatic increase during the recession of 1982. The two series also appear to have a cyclical pattern: Exit rises during recessions, and entry follows it, increasing during the subsequent recovery. This pattern fits the recession of 1974-75 and those occurring from 1980 to 1982. In spite of these cyclical variations, it is clear that not all of the series' fluctuations can be attributed to any particular

[1]Dunne (1992) provides details of the linking process for the ASM panel.

[2]For further details concerning the construction of the entry and exit data, see Davis, Haltiwanger, and Schuh(1995).

Variable	Mean	Std. Dev.	Corr. with ΔGDP
ΔGDP	0.34%	1.14%	1.00
	(0.18%)	(0.14%)	(0.00)
ΔTFP	0.09%	0.84%	0.83
	(0.08%)	(0.07%)	(0.15)
Entry Rate	0.62%	0.23%	0.13
	(0.04%)	(0.04%)	(0.12)
Exit Rate	0.83%	0.26%	−0.32
	(0.06%)	(0.04%)	(0.13)
Exit Rate:	1.67%	1.15%	−0.44
Young Plants	(0.26%)	(0.17%)	(0.12)

Table 1: Summary Statistics

recession. This is particularly true for entry's rise during 1978 and exit's during the mid 1980's. The exit rate for young plants shares many of the overall exit rate's features. In particular, it reached peaks during the 1974-75 recession and during the mid 1980's. An interesting divergence between young plant exit and the exit of all plants occurred during the recession of 1981-82. The overall exit rate achieved its maximum in the sample in late 1981. While the exit rate of young plants was high over this period, it was not drastically above average.

To gain a firmer grasp of entry and exit's cyclical behavior, table 1 reports their summary statistics: their means, standard deviations, and contemporaneous correlations with non-farm, non-government gross domestic product growth. It also reports the same statistics for GDP growth and total factor productivity growth over the same period. Total factor productivity growth is conventionally measured using the definition

$$z_t \equiv y_t - \alpha n_t - (1-\alpha)k_t. \tag{1}$$

The growth rates of GDP, hours worked, and the capital stock are y_t, n_t, and k_t. The elasticity of output with respect to labor input, α, is estimated with labor's average share of output, as in Solow(1957). Standard errors, estimated using Newey and West's(1987) procedure, appear below each estimated moment in parentheses.

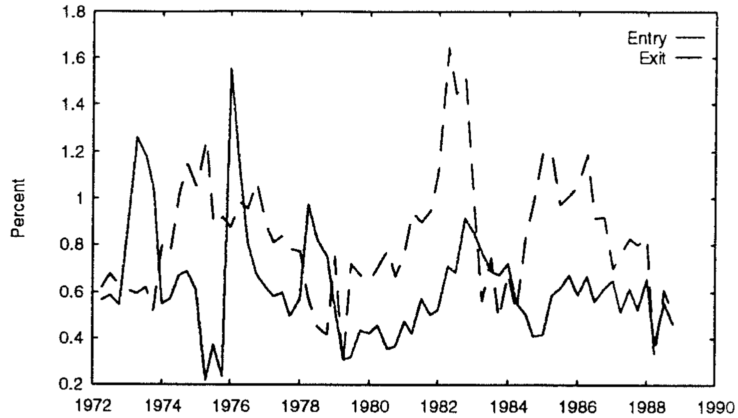

Figure 1: Employment Weighted Entry and Exit Rates

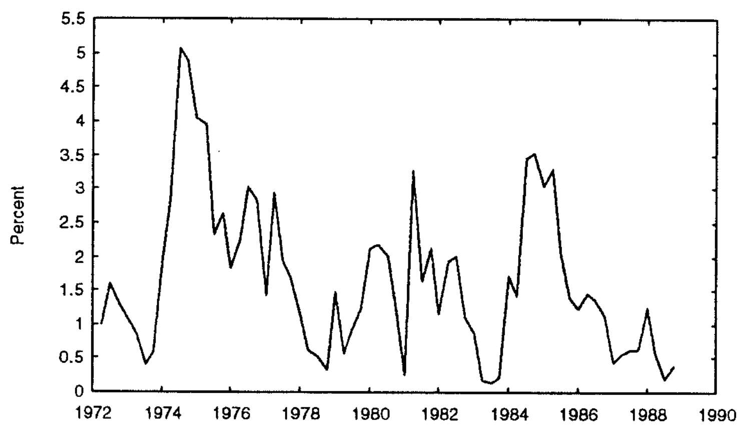

Figure 2: Exit Rate of Plants Less than One Year Old

The entry rate's sample mean is considerably less than the exit rates, 0.62% versus 0.83%, and both series are quite volatile. Their sample standard deviations are 0.23% and 0.26%. The average exit rate for young plants, 1.67%, reflects the declining exit hazard rate. The exit of young plants is extremely volatile: Its sample standard deviation is 1.15%. The contemporaneous correlations with GDP growth reveal cyclical fluctuations of exit, but not of entry. The entry rate's sample correlation with GDP growth is only 0.13, and its standard error is large, casting the estimate's significance into doubt. In contrast, the overall exit rate and that for young plants have large, statistically significant, and negative correlations with GDP growth.

The usefulness of the series' contemporaneous correlations for gauging their business cycle behavior becomes questionable after considering how the data was constructed. Davis, Haltiwanger, and Schuh(1995) report that the quarterly timing of the ASM panel data set is non-standard. Each year, each respondent reports its employment in the previous four quarters, but the year's first quarter begins on November 15 of the *previous* year. Furthermore, the quarters are not all of equal length. Davis, Haltiwanger, and Schuh(1995) correct their reported time series to make their quarters of comparable length, but can not account for the non-standard quarterly timing.

Accordingly, a more complete picture of entry and exit's cyclical behavior requires looking at their leading and lagging correlations with the business cycle. Figures 3, 4, and 5 plot the correlations of entry, overall exit, and exit of young plants with future and past GDP growth. Figure 6 plots the correlations of exit with future and past entry. The figures also present 95% confidence intervals for each point on the graph. They were produced using the same procedure as above. The dynamic correlations reflect the cyclical pattern found in the plot of the data. Exit increases during recessions and entry increases during the subsequent recovery. Such a cyclical pattern implies that exit leads entry.

The entry rate's dynamic correlations confirm its procyclical nature. Although its contemporaneous correlation with GDP growth is small and insignificant, its correlation with GDP growth one period ago is larger, 0.28, and statistically significant. Although neither of entry's correlations with GDP growth two or three quarters ago are statistically significant, their point estimates are large, 0.25 and 0.26. The assertion that this lagging relationship between the measured exit rate and GDP growth reflects a positive *contemporaneous* relationship between the actual entry rate and the business cycle

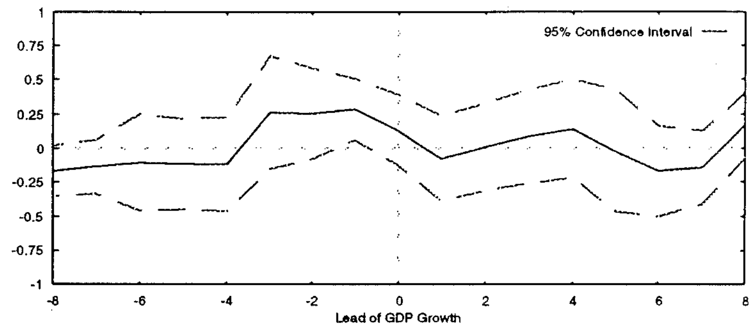

Figure 3: Dynamic Correlations of Entry Rate with ΔGDP

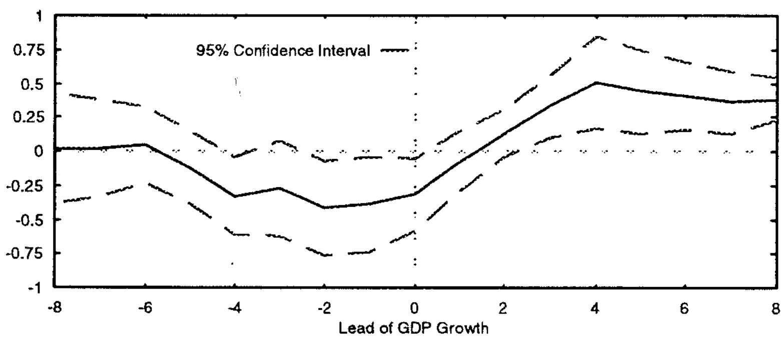

Figure 4: Dynamic Correlations of Exit Rate with ΔGDP

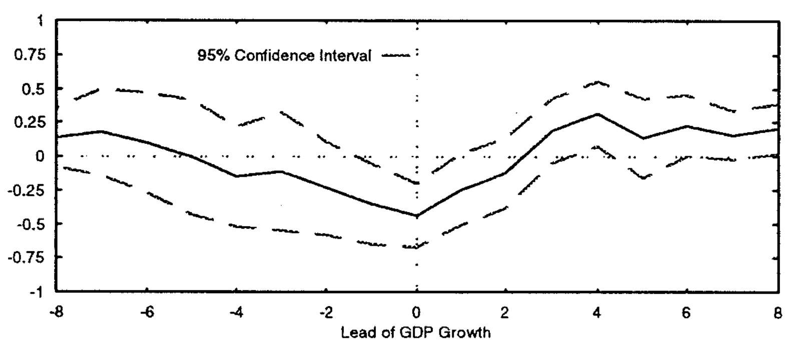

Figure 5: Dynamic Correlations of Young Exit Rate with ΔGDP

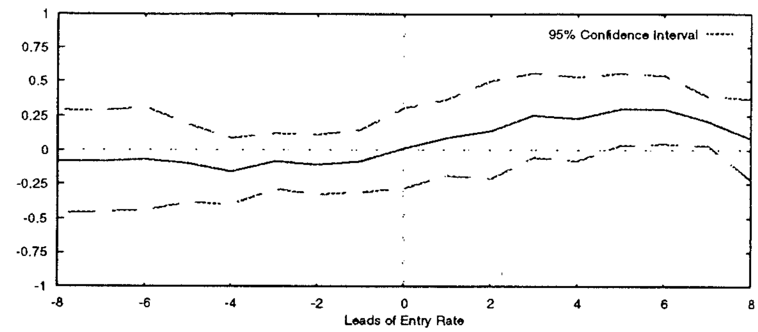

Figure 6: Dynamic Correlations of Exit Rate with Entry Rate

is plausible for two reasons. First, the non-standard quarterly timing of the entry rate series implies that the period over which data is collected for the current entry rate overlaps with the period over which data is collected for the previous quarter's GDP. Second, the Department of Census, in order to account for attrition from the ASM panel, actively collects data from plant start-ups from two sources, the Company Organization Survey and the Social Security Administration. It seems plausible that these sources would tend to identify plant start-ups after, rather than before, their actual births.

The exit rate's dynamic correlations also reflect the cyclical pattern found in the data plot. The exit rate is countercyclical. It has virtually no significant correlation with past GDP growth, but its correlations with future GDP growth are positive, large, and statistically significant. The correlation between the exit rate and GDP growth four quarters hence is 0.51. This positive relationship is persistent: the sample correlation is still large and significant eight quarters into the future. The exit rate for young plants also exhibits this relationship, but it is weaker. Finally, the exit rate has no significant correlation with the current or past entry rates, but it is positively correlated with the entry rate five to seven quarters in the future. These three correlations are 0.30, 0.30, and 0.21. All three of these correlations are individually statistically significant. The long horizon of this measured leading relationship suggests that it is not the product of a contemporaneous relationship and timing problems in the measurement of entry; nevertheless, inferring the exact horizon of the true relationship is difficult.

The dynamic correlations of entry and exit with the business cycle con-

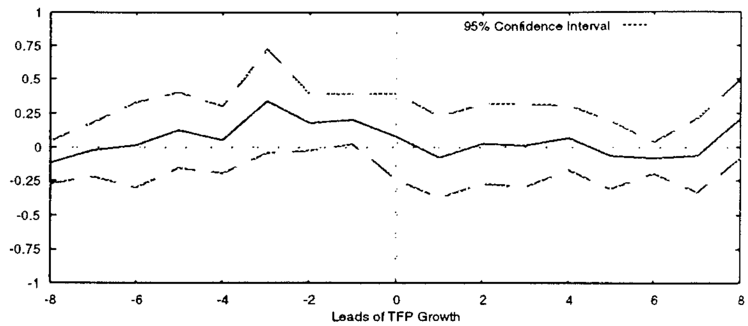

Figure 7: Dynamic Correlations of Entry with ΔTFP

firm the cyclical pattern evident in the data plot, but by themselves they reveal nothing about the U.S. economy's structure or the fluctuations' underlying cause. One hypothesis regarding exit and entry's cyclical pattern is technological: Exit and entry play important roles in the elimination of outdated production methods and the implementation of new technology. To the extent that exit and entry covary with economic activity, technological implementation and retirement are significant causes of the business cycle. This hypothesis played a central role in the business cycle theories of Schumpeter(1927). More recently, Cooley, Greenwood, and Yorukoglu(1993) have studied a vintage capital model in which the replacement of old machinery with new is an important aspect of the business cycle. A preliminary exploration of this hypothesis examines the covariance of entry and exit with conventionally measured total factor productivity. Measured TFP may reflect other factors besides technological change, such as variable factor utilization[3] or market power[4], but the absence of a relationship between it, entry, and exit would be problematic for the technological implementation hypothesis.

Figures 7, 8, and 9 plot the dynamic correlations of the entry rate, the overall exit rate, and the exit rate for young plants with conventionally measured TFP growth. These correlations are strikingly similar to the analogous correlations with GDP growth. First, the dynamic correlations indicate that entry covaries positively with contemporaneous TFP growth. Although the contemporaneous correlation is small, 0.08, and statistically insignificant, the

[3]As in Burnside, Eichenbaum, and Rebelo(1990) and Summers(1986).
[4]As in Hall(1988).

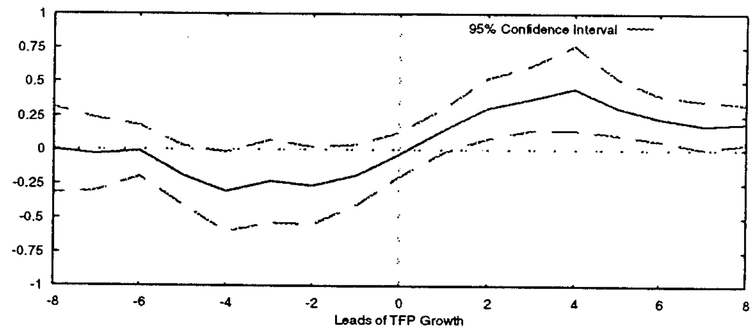

Figure 8: Dynamic Correlations of Exit Rate with ΔTFP

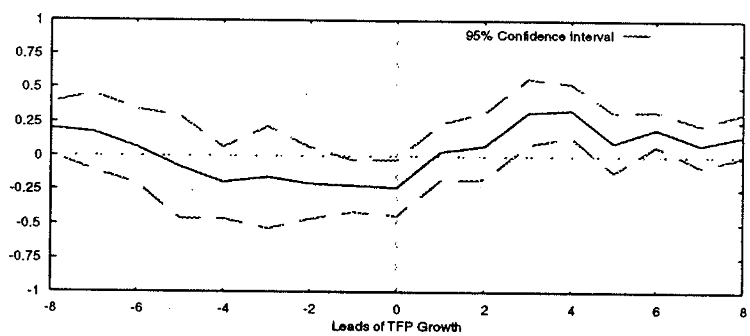

Figure 9: Dynamic Correlations of Young Plant Exit with ΔTFP

correlation with TFP growth one quarter ago is larger, 0.20, and statistically significant. Although the correlations two and three quarters in the past are statistically insignificant, their point estimates are large, 0.18 and 0.34. Second, the exit rate covaries positively with future productivity growth. Its correlations with TFP growth three, four, and five quarters hence are 0.38, 0.45, and 0.32. These point estimates are all statistically significant. The exit rate of young plants has a similar, but weaker, relationship with TFP growth. The exit rate's contemporaneous correlation with TFP growth is noticeably different from the same correlation with GDP growth. Whereas exit covaries negatively with contemporaneous GDP growth, it does not covary at all with contemporaneous TFP growth. The exit rate of young plants does covary negatively with TFP growth, but the correlation's magnitude is much smaller than the analogous correlation with GDP growth.

The preliminary empirical work indicates that there is an association of entry and exit with total factor productivity growth, so the hypothesis that cyclical fluctuations in entry and exit reflect the implementation of technological progress has withstood its first test. The remainder of this paper carries the investigation further by constructing and analyzing a computable general equilibrium economy which embodies the hypothesis that fluctuations in entry and exit reflect the implementation of new technology.

3 The Model

The model of this section differs from a standard equilibrium macroeconomic framework by explicitly modeling the heterogeneity among plants which drives entry and exit. Investing one unit of an aggregate good yields a unit mass of plants. Plant construction requires time to deliver. As in the vintage capital environments of Solow (1960; 1962a; 1962b), Greenwood, Hercowitz, and Krusell (1992), and Cooley, Greenwood and Yorukoglu (1993), only newly constructed plants have access to the leading edge technology. Entering plants implement the leading edge technology with varying degrees of success. A plant's technology is fixed throughout its lifetime. After birth, plants are subject to ongoing idiosyncratic productivity shocks. Any plant can be retired to recover a fraction of its capital stock as scrap. This scrap value does not depend on a plant's productivity, so only relatively unproductive plants will exit.

The remainder of the model is standard. There are many identical consumers who provide the economy's labor and own its equity. Capital goods are traded in complete markets. As in Prescott and Mehra(1980), a single representative firm purchases all available capital goods from the consumers at the beginning of the period and liquidates after production. Its manager chooses the allocation of labor among the plants and makes plant exit decisions to maximize the firm's profits. The constant returns to scale technology ensures that profits are zero in a competitive equilibrium.

This section describes the technology available to the model economy's production sector, the representative consumer's preferences and endowments, and the physical environment within which they operate. Section 4 describes the market structure, presents the agents' optimization problems, and defines a competitive equilibrium.

3.1 The Production Sector

A continuum of atomistic plants populates the economy's production sector. A plant uses labor to produce an aggregate good, which can be used for either consumption or new plant construction. A Cobb-Douglas production function characterizes each plant's technology.

$$y = (ke^{v_t})^{1-\alpha} n^{\alpha}. \tag{2}$$

The plant's capital is k; its labor input is n; and its output of the aggregate good is y. The plant's idiosyncratic productivity level is v_t. The elasticity of output with respect to labor input, $0 < \alpha < 1$, is common across plants. Because this technology obeys constant returns to scale, the plants' size distribution (as measured by capital) does not affect the economy's aggregate production possibilities. The production sets available to a single plant with one unit of capital and N otherwise identical plants, each with $k = 1/N$, are the same. This allows considerable simplification of the economy by restricting the size of all plants to equal 1.

New plant construction requires time to deliver. Investing a unit of the aggregate good in construction yields a plant in T^i periods. A new plant has access to the leading edge production process when its construction begins. After its construction, a plant may not update its technology or add to its capital stock. A plant's initial idiosyncratic productivity level reflects its success or failure at implementing this technology. The initial productivity level, v_{t+T^i}, of a plant begun in period t is a random variable with a normal distribution.

$$v_{t+T^i} \sim N(z_t, \sigma_e^2) \tag{3}$$

The productivity of a plant with an average implementation of the leading edge production process is z_t. This is an index of the leading edge technology. It follows a random walk with a positive drift.

$$\begin{aligned} z_t &= \mu_z + z_{t-1} + \varepsilon_t^z \\ \varepsilon_t^z &\sim N(0, \sigma_z^2) \end{aligned} \tag{4}$$

The exogenous technological progress embodied in z_t is the model economy's only source of growth and aggregate uncertainty. After a new plant's entry, nothing distinguishes it from an incumbent with an identical productivity level.

After production, a plant may either remain in place until the next period or be retired. If it is retired, η units of the aggregate good are recovered as its scrap value. The scrap value is positive but less than one. Alternatively, the plant may be left intact. In that case, it receives an idiosyncratic shock to its productivity level before the next period.

$$\begin{aligned} v_{t+1} &= v_t + \varepsilon_{t+1} \\ \varepsilon_{t+1} &\sim N(0, \sigma^2) \end{aligned} \tag{5}$$

That is, the plant's idiosyncratic productivity level follows a random walk. The unit root in the plant productivity process implies that the level of the leading edge production technology during its construction, z_t, will have a permanent effect on its productivity. In this sense, the model includes vintage capital effects. The random walk's innovation is *i.i.d.* across time and across plants. It has zero mean, so an average plant's productivity does not rise over its lifetime.

3.2 Consumers

There are many identical, infinitely lived consumers who value two goods, consumption and leisure. Each consumer has a time endowment of one unit each period, which she must allocate between leisure and labor. The utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, 1 - n_t)$$

represents her preferences over state contingent sequences of these two goods. Her discount factor is β, which lies strictly between zero and one. Her momentary utility function, $u(c_t, 1 - n_t)$, is

$$u(c_t, 1 - n_t) = \ln(c_t) + \kappa(1 - n_t) \tag{6}$$

where $\kappa > 0$. Hansen(1985) justifies this functional form for preferences in a real business cycle model in which labor is indivisible and consumers trade lotteries over employment outcomes.

4 Competitive Equilibrium

In a competitive equilibrium, the economy's agents trade the aggregate good, labor, and capital goods of all productivity types in complete markets. This section begins by outlining the model economy's market structure. This particular market structure clarifies the correspondence between the economy's competitive equilibrium and the solution to its social planning problem. Summaries of the firms' and consumers' maximization problems follow this, and market clearing conditions complete the model's exposition. The section concludes with a discussion of computational issues.

4.1 Market Structure

Three types of agents populate the model economy, production firms, construction firms, and consumers. They trade capital goods, labor, and the aggregate consumption good in competitive markets. The prices for capital goods are the basis of entry and exit decisions. The market structure of Prescott and Mehra(1980) automatically provides these prices.

At the beginning of each period, each consumer owns two types of assets, a portfolio of the economy's operational plants and another of construction projects at various stages of completion. They sell the operational plants and their labor services to the production firms. Production firms only exist for one period. They produce the aggregate good with the technology described by equation 2. After production, the firms decide which of the surviving plants to keep intact and which to salvage for their scrap value. Then the firms sell their stock of the aggregate good, consisting of what they produced and recovered as scrap, to the consumers and the construction firms. The aggregate good is the numeraire, and its spot price always equals one. It is perishable, so the consumer must consume her purchases within the current period. The construction firms also exist for only one period. They purchase the aggregate good from the production firm and plants under construction from the consumer. They turn the oldest construction projects into new plants and advance the younger projects towards completion. At the end of the period, firms in both the production sector and the construction sector liquidate, selling their plants and construction projects to the consumers. Between periods, the operational plants receive their productivity innovations.

This market structure, as opposed to one in which consumers rent capital goods to firms every period, naturally prices the economy's capital assets.[5] The technology available to firms in both sectors obeys constant returns to scale. Therefore, firms earn zero profits in equilibrium. As in a standard macroeconomic model, each sector acts as if it has a single, representative, price taking firm. This division of the production sector into two representative firms is arbitrary but pedagogically useful.

4.2 The Production Sector

Given the prices of all plants and the wage rate, the representative production manager hires labor and trades plants to maximize its profits. The wage rate in period t is w_t, the price of a plant with productivity level v_t at the beginning of the period is $q_t^0(v_t)$, and the analogous price at the end of the period is $q^1(v_t)$. If asset prices equal discounted expected dividend streams, then asset prices will be increasing in v_t. A plant's scrap value is invariant to its productivity, so the representative firm will choose to scrap only those plants below a threshold, $\underline{v}_t$. Those plants with productivity levels above the threshold will remain in production. This threshold scrap rule is similar to those found in Hopenhayn (1992a) and Jovanovic (1982). The representative firm chooses the number and types of plants to purchase at the beginning of the period, the amount of labor to hire, its distribution across the plants,

[5] Additional markets in state contingent claims on capital assets and the aggregate good could be added at the expense of considerable extra notation, but spot market prices for physical assets would not change.

and the exit threshold to maximize its current profits.

$$\max_{k(v_t),n,n(v_t),\underline{v}_t} y + \eta \int_{-\infty}^{\underline{v}_t} k(v_t)dv_t$$

$$+ \int_{\underline{v}_t}^{\infty} q_t^1(v_t)k(v_t)dv_t - \int_{-\infty}^{\infty} q_t^0(v_t)k(v_t) - w_t n \tag{7}$$

$$\text{subject to: } y = \int_{-\infty}^{\infty} k(v_t)e^{v_t(1-\alpha)}n(v_t)^{\alpha}dv_t$$

$$n = \int_{-\infty}^{\infty} k(v_t)n(v_t)dv_t$$

The objective function's first two terms are the firm's total output and the salvage value of the plants it retires. The third term is the value of its remaining plants at the end of the period. The final terms are the cost of its beginning of period plant purchases and its wage bill. The first constraint on the firm's problem says that summing the output of all plants yields the firm's total output. The amount of labor the firm assigns to a single plant with productivity v_t is $n(v_t)$. The second constraint restricts the total labor allocated among the plants to equal that hired by the representative firm.

The envelope theorem allows this problem to be broken into two steps. First consider the problem of maximizing the firm's output given its capital and labor inputs. This is the labor allocation problem.

$$y = \max_{n(v_t)} \int_{-\infty}^{\infty} k(v_t)e^{v_t(1-\alpha)}n(v_t)^{\alpha}dv_t$$

$$\text{subject to: } n = \int_{-\infty}^{\infty} k(v_t)n(v_t)dv_t \tag{8}$$

This problem has a simple and familiar solution. Define the firm's *effective capital stock* to be

$$\bar{k} = \int_{-\infty}^{\infty} e^{v_t}k(v_t)dv_t. \tag{9}$$

The effective capital stock is the sum of the number of plants of each type, weighted by their productivity level. The solution to the labor allocation problem is

$$n(v_t) = ne^{v_t}/\bar{k}.$$

A plant's labor input is proportional to its productivity. Substituting this into the firm's production function yields

$$y = \bar{k}^{1-\alpha}n^{\alpha}. \tag{10}$$

A Cobb-Douglas production function in labor and *effective* capital represents the aggregate production possibilities. Using the same functional form, Solow (1960) derived this result in a model of vintage capital.

Substituting the solution to the labor allocation problem into the profit maximization problem yields

$$\begin{aligned} \max_{k(v_t),n,\underline{v}_t} \bar{k}^{1-\alpha}n^{\alpha} + \eta \int_{-\infty}^{\underline{v}_t} k(v_t)dv_t + \int_{\underline{v}_t}^{\infty} q_t^1(v_t)k(v_t)dv_t & \\ - \int_{-\infty}^{\infty} q_t^0(v_t)k(v_t)dv_t - w_t n & \qquad (11) \\ \text{subject to: } \bar{k} = \int_{-\infty}^{\infty} e^{v_t}k(v_t)dv_t & \end{aligned}$$

The first order conditions for this problem are

$$w_t = \alpha \left(\frac{\bar{k}}{n}\right)^{1-\alpha} \qquad (12)$$

$$\eta = q_t^1(\underline{v}_t) \qquad (13)$$

$$q_t^0(v_t) = (1-\alpha)\left(\frac{\bar{k}}{n}\right)^{-\alpha} e^{v_t} + 1\{v_t < \underline{v}_t\}\eta + 1\{v_t \geq \underline{v}_t\}q_t^1(v_t) \qquad (14)$$

The indicator function, $1\{\cdot\}$, equals one if its argument is true and zero otherwise. Equation (12) is a standard labor demand condition equalizing the marginal product of labor and the wage rate. Equation (13) defines the firm's optimal choice of the exit threshold. It says that the scrap value of the marginal plant must equal its end of period asset price if left in place. Equation (14) is an asset pricing equation. It constrains an asset's beginning of period price to equal the dividends it returns plus its value at the end of the period. If the asset is scrapped, this value equals that of the scrap capital. Otherwise, it equals its price at the end of the period.

4.3 The Construction Sector

A large number of construction firms use a one to one technology to convert the aggregate good into new plants. A construction firm which buys one unit of the aggregate good can produce a construction project one period old. The price of such a construction project is $q_t^{1i}(1)$. The zero profit condition associated with this transaction is

$$1 = q_t^{1i}(1) \tag{15}$$

Similarly, a firm purchasing a construction project j periods old at the beginning of the period for $q_t^{0i}(j)$ can sell it at the end of the period for $q_t^{1i}(j+1)$. For no profit opportunity to exist, these prices must be equal.

$$q_t^{0i}(j) = q_t^{1i}(j+1) \quad j = 1 \ldots T^i - 1 \tag{16}$$

4.4 The Consumer's Problem

Each consumer maximizes her expected utility by choosing state contingent sequences of consumption, labor, and asset holdings taking wages, asset prices, and her initial asset holdings as given.

$$\max_{\substack{\{c_t\}_{t=0}^{\infty}, \{n_t\}_{t=0}^{\infty}, \{k_t^0(v_t)\}_{t=1}^{\infty}, \\ \{k_t^1(v_t)\}_{t=0}^{\infty}, \{i_t^j\}_{t=1}^{\infty}}} E_0 \sum_{t=0}^{\infty} \beta^t (\ln(c_t) + \kappa(1 - n_t))$$

subject to:

$$\begin{aligned} 0 &= c_t + \textstyle\int_{-\infty}^{\infty} q_t^1(v_t) k_t^1(v_t) dv_t + \sum_{j=1}^{T^i} q_t^{1i}(j) i_{t+1}(j) \\ &\quad - w_t n_t - \textstyle\int_{-\infty}^{\infty} q_t^0(v_t) k_t^0(v_t) dv_t - \sum_{j=1}^{T^i-1} q_t^{0i}(j) i_{t-1}(j) \\ k_{t+1}^0(v_{t+1}) &= \textstyle\int_{-\infty}^{\infty} \frac{1}{\sigma} \phi\left(\frac{v_{t+1}-v_t}{\sigma}\right) k_t^1(v_t) dv_t + \frac{1}{\sigma_e} \phi\left(\frac{v_{t+1}}{\sigma_e}\right) i_t(T^i) \\ k_0^0(v_t),\ & i_0(j) \quad j = 2, \ldots, T^i - 1 \quad \text{given} \end{aligned} \tag{17}$$

The consumer's holdings of construction projects j periods old at the end of period t is $i_t(j)$. Her holdings of plants at the beginning and end of period t are $k_t^0(v_t)$ and $k_t^1(v_t)$. The first constraint in (17) is the static budget constraint. The second summarizes how productivity innovations at the plant level change the consumer's portfolio between periods. In addition to these two constraints, the necessary conditions for a solution to the consumer's problem are

$$\frac{1}{c_t} q_t^1(v_t) = E_t \beta \frac{1}{c_{t+1}} \int_{-\infty}^{\infty} \frac{1}{\sigma} \phi\left(\frac{v_{t+1} - v_t}{\sigma}\right) q_{t+1}^0(v_{t+1}) dv_{t+1} \tag{18}$$

$$\frac{1}{c_t} q_t^{1i}(j) = E_t \beta \frac{1}{c_t} q_t^{0i}(j) \int_{-\infty}^{\infty} \frac{1}{\sigma_e} \phi\left(\frac{v_{t+1} - z_{t+1-T^i}}{\sigma_e}\right) q_{t+1}^0(v_{t+1}) dv_{t+1} \quad (19)$$

$$\frac{1}{c_t} q_t^{1i}(T^i) = E_t \beta \frac{1}{c_{t+1}} \int_{-\infty}^{\infty} \frac{1}{\sigma_e} \phi\left(\frac{v_{t+1} - z_{t+1-T^i}}{\sigma_e}\right) q_{t+1}^0(v_{t+1}) dv_{t+1} \quad (20)$$

$$(21)$$

$$\frac{1}{c_t} w_t = \kappa \quad (22)$$

Equations (18) and (19) are familiar from the asset pricing literature. They restrict the expected product of the intertemporal marginal rate of substitution with the returns to holding any asset to equal one. Equation (20) equates the price of a plant just prior to its completion with its expected equity price. Equation (22) is a standard static labor supply equation. A set of decisions for consumption, labor supply, and asset holdings will be a solution for this problem if they satisfy equations (18), (19), (22), and the transversality condition,

$$\lim_{t \to \infty} E_0 \beta^t \frac{1}{c_t} \left(\int_{-\infty}^{\infty} q_t^0(\theta) k_t(\theta) d\theta + \sum_{j=2}^{T^i - 1} q_t^{0i}(j) i_{t-1}^j \right) = 0. \quad (23)$$

4.5 Market Clearing and Equilibrium

In a competitive equilibrium the firms' and consumers' problems are connected through the imposition of market clearing conditions. A competitive equilibrium for the economy is a state contingent sequence of consumption, $\{C_t\}_{t=0}^{\infty}$, labor, $\{N_t\}_{t=0}^{\infty}$, construction projects, $\{I_t^j\}_{t=0}^{\infty}$ beginning and end of period plant holdings, $\{K_t^0(v_t)\}_{t=1}^{\infty}$ and $\{K_t^1(v_t)\}_{t=1}^{\infty}$, exit thresholds, $\underline{v}_t$, wage rates, $\{w_t\}_{t=0}^{\infty}$, beginning and end of period construction project prices, $\{q_t^{0i}(j)\}_{t=1}^{\infty}$ and $\{q_t^{1i}(j)\}_{t=1}^{\infty}$, and beginning and end of period plant prices, $\{q_t^0(v_t)\}_{t=0}^{\infty}$ and $\{q_t^1(v_t)\}_{t=0}^{\infty}$, such that

1. $\{C_t\}_{t=0}^{\infty}$, $\{N_t\}_{t=0}^{\infty}$, $\{K_t^0(v_t)\}_{t=1}^{\infty}$, $\{K_t^1(v_t)\}_{t=1}^{\infty}$, and $\{I_t^j\}_{t=0}^{\infty}$ is a solution to the consumer's problem given $\{w_t\}_{t=0}^{\infty}$, $\{q_t^0(\theta), q_t^1(\theta)\}_{t=0}^{\infty}$ and $\{q_t^{0i}(j), q_t^{1i}(j)\}_{t=1}^{\infty}$.
2. $K_t^0(v_t)$, $K_t^1(v_t)$, $\underline{v}_t$, and N_t solve the representative production firm's problem at time t given w_t, $q_t^0(v_t)$, and $q_t^1(v_t)$.
3. q_t^{0i}, q_t^{1i}, and $q_t^0(v_t)$ satisfy the zero profit conditions (15) and (16).

4. The production firm earns zero profits.

4.6 Computational Issues

In general no analytical expression exists for the economy's competitive equilibrium, but its approximate computation is feasible. The first and second welfare theorems apply to the model economy, so the problem of computing a competitive equilibrium can be conveniently recast as solving a social planning problem.

$$\max_{\substack{\{C_t\}_{t=0}^{\infty}, \{N_t\}_{t=0}^{\infty}, \{I_t^j\}_{t=0}^{\infty}, \\ \{\bar{K}_t\}_{t=0}^{\infty}, \{\underline{v}_t\}_{t=0}^{\infty}, \{K_t(v_t)\}_{t=1}^{\infty}}} \quad E_0 \sum_{t=0}^{\infty} \beta^t (\ln(C_t) + \kappa(1 - N_t))$$

subject to:

$$\begin{aligned} 0 &= C_t + I_t^1 - \bar{K}_t^{1-\alpha} N_t^{\alpha} - \eta \int_{-\infty}^{\underline{v}_t} K_t(v_t) dv_t \\ \bar{K}_t &= \int_{-\infty}^{\infty} e^{v_t} K_t(v_t) dv_t \\ I_t^j &= I_{t-1}^{j-1} \quad j = 2, \ldots, T^i \\ K_{t+1}(v_{t+1}) &= \int_{\underline{v}_t}^{\infty} \frac{1}{\sigma} \phi\left(\frac{v_{t+1} - v_t}{\sigma}\right) K_t(v_t) dv_t \\ &\quad + \frac{1}{\sigma_e} \phi\left(\frac{v_{t+1} - z_{t+1-T^i}}{\sigma_e}\right) I_{t-T^i+1} \end{aligned} \tag{24}$$

The solution to this problem is a set of decision rules expressing the social planner's choice variables as functions of the current state, $K_t(v_t)$, and the exogenous shock, z_t.

The solution of similar social planning problems is common in the real business cycle literature. What distinguishes this problem from those previously studied is the nature of the choice variable, $K_t(v_t)$. Because it is a function rather than a scalar, the standard solution methods are not immediately applicable. This hurdle is overcome by using quadrature approximations of the relevant functional equations. This approximation reduces a functional dynamical system to a standard vector dynamical system with a large, but finite, state space. Applying standard methods for solving linear dynamical systems then produces the desired solution.

Eliminating all sources of non-stationarity is the first step in solving a problem like (24). First note that the center of the distribution $K(v_t)$ will continually shift to the right as z_t grows. The aggregate production function is Cobb-Douglas in capital and labor, so the capital augmenting technological change can be expressed in labor augmenting form. Define a plant's productivity relative to the previous period's leading edge technology as $u_t \equiv v_t - z_{t-1}$ and the density of u_t as $K_t^T(u_t) \equiv K_t(u_t + z_{t-1})$. The location of $K_t^T(u_t)$ does not move to the right over time. With this notation, the aggregate production function can be re-written as

$$Y_t = (e^{\frac{1-\alpha}{\alpha}z_{t-1}}N_t)^\alpha(\int_{-\infty}^{\infty} e^{u_t}K_t^T(u_t)d\theta)^{1-\alpha} \tag{25}$$

So technological improvement augments labor rather than capital. Written like this, the economy satisfies the balanced growth restrictions of King, Plosser, and Rebelo (1987; 1988a; 1988b). As in that work, scaling all of the social planner's choice variables but hours worked by $e^{\frac{1-\alpha}{\alpha}z_{t-1}}$ yields a social planning problem for an equivalent economy which is stationary.

To find an approximate solution to this social planning problem, replace its first order necessary conditions with log-linear approximations around its steady state. Because the capital stock is a function rather than a scalar, these approximate first order conditions are *functional* equations. Quadrature approximations, the evaluation of which only requires the function's values at a finite number of points, replace the functional equations.[6] This approximation produces a finite dimensional linear dynamical system. Although its dimension is much greater than that of a standard problem, its solutions can be found by applying standard linear algebraic techniques.

The approximate system of equations possesses a continuum of solutions. The unique one which also satisfies the social planning problem's transversality condition is an approximate solution to the scaled economy's social planning problem. Rescaling the solution by $e^{\frac{1-\alpha}{\alpha}z_{t-1}}$ yields the desired approximate solution to the original problem.

The log-linear nature of the approximation method yields decision rules of the form

$$\begin{aligned} \ln(K_{t+1}(u_{t+1})) &= G(\ln(K_t(u_t), z_t) \\ \ln(N_t) &= H(\ln(K_t(u_t), z_t) \\ &\vdots \end{aligned} \tag{26}$$

[6]See Press, Teukolsky, Vetterling, and Flannery (1992) for an explanation of quadrature approximation of integrals.

The functionals $G(\cdot,\cdot)$ and $H(\cdot,\cdot)$ are linear in their arguments. Composing $G(\cdot,\cdot)$ with itself produces the moving average representation of $\ln(K_t(u_t))$ in terms of z_t. The moving average representations of all the other variables can then be computed using the approximate log-linear policy functions. With these in hand, computing the correlations and standard errors for stationarity inducing transformations of the endogenous variables is straightforward. A computational appendix to this paper, available upon request, describes this solution strategy in greater detail.

5 The Model's Stochastic Behavior

Can the above model of entry and exit reasonably account for the cyclical fluctuations in entry and exit? This section addresses this question by studying a parameterized version of the model. As in Kydland and Prescott(1982), the parameter values match features of the model's steady state growth path with average quantities of the U.S. economy. Some of the model's parameters are familiar from previous quantitative work using the stochastic one-sector growth model[7], so the analogous values are used here.

Two parameters characterize the consumer's preferences. β, the consumer's rate of time preference, and κ, her constant marginal utility of leisure. Along the steady state growth path, β equals the inverse of the risk free gross interest rate. This is set to equal a 3% annual rate, so that $\beta = 1.03^{-\frac{1}{4}}$. The marginal utility of leisure is set so that 0.26 of the consumer's time endowment is spent at work. Because the model's labor and product markets are competitive, the elasticity of output with respect to labor input, α, equals labor's share of output. Accordingly, this is set equal to 2/3, labor's average share in the U.S. economy. The model's steady state growth rate of output equals $\frac{1-\alpha}{\alpha}\mu_z$. Given a value for α, μ_z is chosen to match this with the average growth rate of the U.S. economy between 1972 and 1988, 0.33% per quarter.

In equilibrium a plant's employment is proportional to its productivity level. Therefore, the cross-sectional variance of plant employment growth rates consistently estimates σ^2. [8] The LRD's observations of plant level employment growth are not publicly available, so a value of σ was inferred

[7] See, for example, King, Plosser, and Rebelo (1988a; 1988b).

[8] This is the case because plants are assumed to operate for one period before exiting. If this is not the case, then such an estimate must be corrected for sample selectivity.

from a regression with this data reported by Hopenhayn and Rogerson(1993). They report a regression of plant employment on a constant and the same plant's employment five years earlier. Ignoring problems due to endogenous sample selection, the model implies that this regression should have a coefficient of unity on lagged plant employment and an innovation standard deviation equal to $20 \times \sigma$. Accordingly, the value of σ used below equals the standard deviation of the regression's residuals divided by 20.

Two of the model's remaining parameters, η and σ_e, are set to match exit rates from the model and the U.S. economies. It is clear that raising η increases the return to closing an unproductive plant and so induces more exit. How σ_e determines exit rates is less obvious. Two features of the plant level productivity process make σ_e an important determinant of exit. First, embodied technological progress implies that each cohort of new entrants will be more productive than the previous cohort. Second, plants with the same productivity level but different birth dates are identical. With nothing to offset them, these features will counterfactually imply that older plants exit more frequently than new entrants. The addition of substantial idiosyncratic uncertainty surrounding a plant's initial draw of v_t can remedy this problem. If σ_e is much larger than σ, then the probability of a new entrant falling below the exit threshold will be higher than that of an incumbent plant with $v_t = z_t$ doing so. Accordingly, a non-linear solution technique was used to chose η and σ_e to match the model's steady state overall exit rate and that for young plants with the average exit rates in the U.S. economy. The standard deviation of the innovation to embodied technological progress, σ_z, was set equal to 0.65%. This implies that the standard deviation of the exit rate in the model economy is 0.25%, about the same as in the U.S. economy. Finally, the time to deliver, T^i, was set to 5. This seems to be about the horizon over which exit leads entry. Table 2 summarizes the parameter values used below.

5.1 Impulse Response Functions

To summarize the model's stochastic behavior, figures graph the response of its key aggregate variables to a one percent improvement in the leading edge technology. Figure 10 graphs the response of the overall exit rate, the exit rate for young plants[9], and the entry rate to a one percent improvement in

[9]Young plants are defined to be between one and four quarters old.

Parameter	Value
β	$1.03^{-\frac{1}{4}}$
μ_z	0.66%
α	2/3
σ	3.64%
σ_ϵ	25%
η	0.85
σ_z	0.65%
T^i	5
N_0	0.26

Table 2: Parameter Values

the leading edge technology. The exit threshold rises 1.06% following a 1% increase in z_t. It then slowly falls towards its new long-run level 1% higher than before the shock. The jump in the exit threshold causes the following quarter's exit rate to increase by 0.30%. This is a sizeable increase relative to the exit rate's mean, 0.83%. The impact of the technology shock on the exit rate is persistent: The exit rate is 0.10% higher three quarters after the shock. The exit rate for young plants differs quantitatively and qualitatively from the overall exit rate. It too rises immediately after a shock, but its ascension is not as steep; it rises only 0.18%. Furthermore, its mean is much larger than the overall exit rate, 1.30%. Its decline thereafter is much more drastic. After six quarters, entrants exit less frequently than average. The entry rate mimics the exit rate, but with a lag due to the time to deliver investment technology. Five quarters following the improvement, the entry rate jumps 0.45%. This jump is persistent, being 0.10% above its steady state value after eight quarters.

Figures 11 and 12 graph the impulse response functions for output, measured TFP, employment, and the effective capital stock. Because the aggregate production function is Cobb-Douglas in labor and effective capital, conventionally measured TFP should equal zero if the correct measure of capital input, $\overline{K}_t$, is used. The measure reported in figure 11 is computed using a perpetual inventory capital measure, $\widehat{K}_t$. This measure is constructed to satisfy the difference equation

$$\widehat{K}_t = (1 - \widehat{\delta})\widehat{K}_{t-1} + \widehat{I}_t.$$

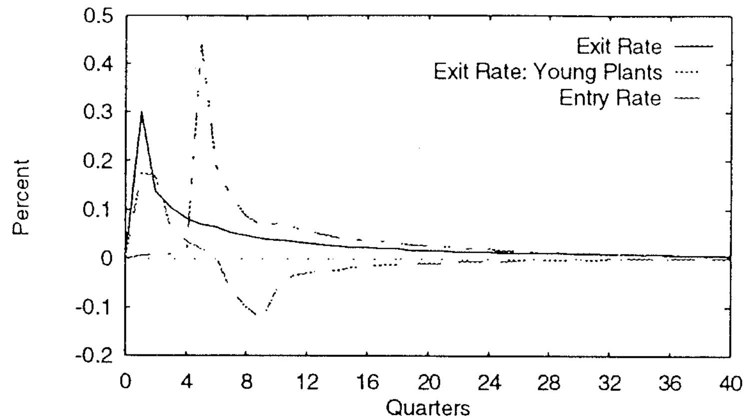

Figure 10: Responses of Entry and Exit

The measured depreciation rate, $\widehat{\delta}$, is set equal to the fraction of capital lost to exit each quarter, about 0.0025. Net investment $\widehat{I}_t$ is defined to equal new construction projects begun minus scrap capital returned from exiting plants.

Because the technology shock increases the productivity of new plants, it decreases the price of investment goods relative to consumption. As in Barro and King (1984) and Greenwood, Hercowitz, and Huffman (1988), if the substitution effect of the relative price change outweighs the income effect, then the consumer will delay gratification, by consuming less and working more, to increase her investment in physical capital. In the model, the substitution effect dominates, so employment increases, nearly 0.4% in the period of the shock. It declines towards its steady state level for four quarters, then slightly rises following the entry of the new plants. The increase in exit of all plants causes the effective capital stock to decline. The magnitude is slight at first, but as better plants exit, the impact becomes more severe. After four quarters, the effective capital stock declines 0.6%. It begins to rise when the first wave of entrants becomes operational. Thereafter, it steadily climbs towards its new steady state value as both the quantity and quality of plants increase. By construction, the perpetual inventory capital stock measure is smooth, so measured TFP mimics the response of the effective capital stock. The immediate increase in employment following the shock causes output to expand. Thereafter, it falls as both hours worked and capital input decline.

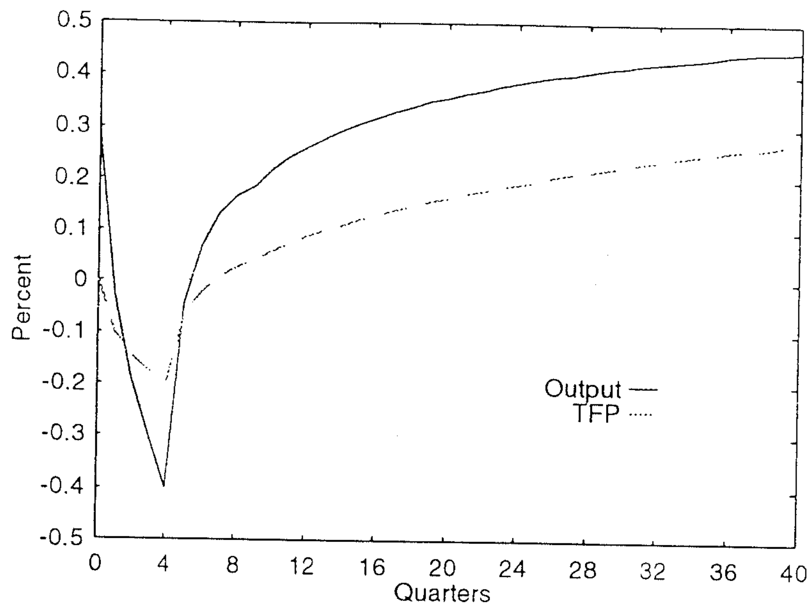

Figure 11: Responses of Output and TFP

After three quarters, output is actually *below* its previous steady state level. Output rises again when the first entrants add to the economy's effective capital stock.

Labor and capital are complements in a Cobb-Douglas production function, so the increase in hours worked and the decrease in the effective capital stock imply that the rental rate for capital services increases immediately following an improvement in the leading edge technology. The immediate returns to remaining in production increase, yet so does exit. The solution to this paradox lies in the irreversibility of exit. Once made, the decision to exit cannot be reversed. Furthermore, each plant experiences ongoing uncertainty about its future productivity. As Dixit and Pindyck(1994) note, these two factors imply that a rational manager may leave an unproductive plant active while waiting to see if its productivity improves. If not for that possibility, the marginal plant would have exited long ago. An improvement in z_t lowers the price of capital goods relative to consumption in the long run. This lowers the probability that, if left in place, a plant's value will ever surpass its scrap value. The option to remain in production becomes less valuable, so the plant exits.

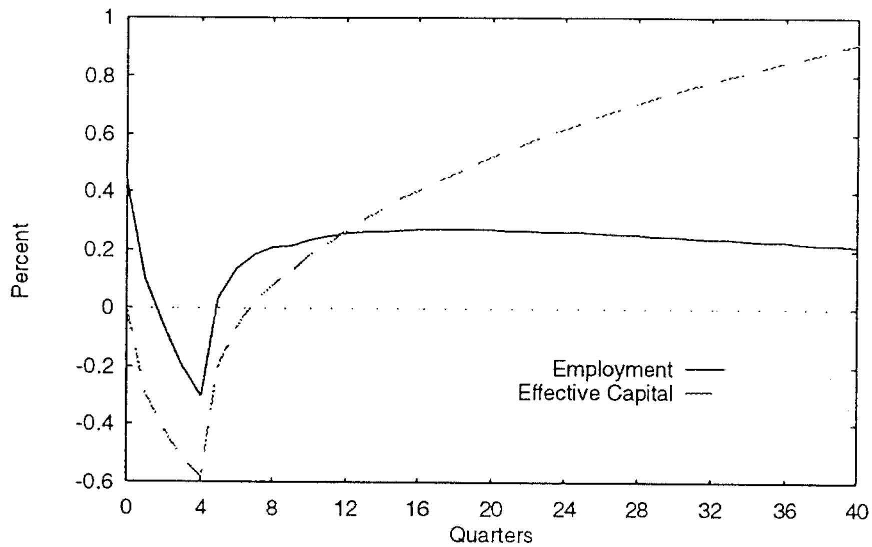

Figure 12: Responses of Employment and Effective Capital

The steady state productivity distribution and exit threshold reflect exit's irreversibility and plants' ongoing productivity. Figure 13 graphs the distribution of productivity across all plants and the exit threshold in the steady state of the estimated model. When an incumbent's productivity is 12.8% lower than the leading edge, it provides the same expected capital services as would a smaller, more productive entrant produced from scrapping the old plant and investing the proceeds. Yet exit does not occur until a plant provides 49.3% less capital services than an average entrant. The idiosyncratic uncertainty has driven a considerable wedge between the plant's material scrap value and the exit threshold. Although a plant's productivity may be low today, the option to operate it tomorrow if its fortunes improve is valuable. Accounting for this option value causes a considerable, although rational, delay in exit.

5.2 Population Moments

The timing of the exit and entry decisions and their impact on output and productivity, determined by the endogenous option value considerations and

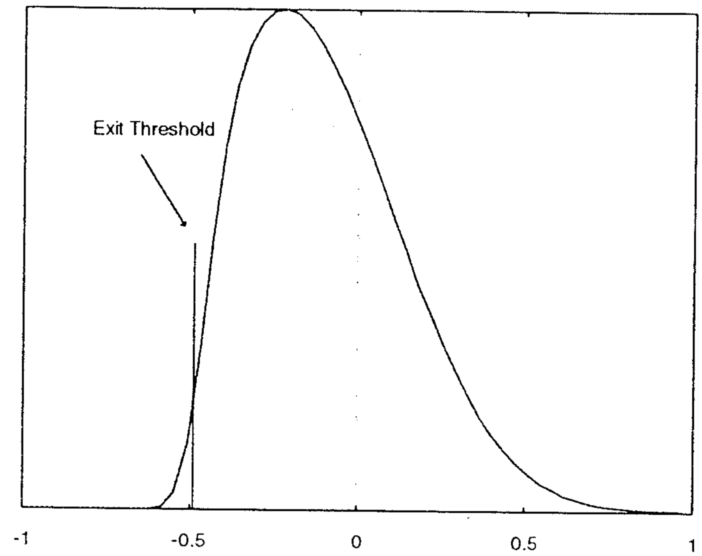

Figure 13: Steady State Distribution of $v_t - z_t$

Variable	Mean	Std. Dev.	Corr. with ΔGDP
ΔGDP	0.34%	0.38%	1.00
ΔTFP	0.22%	0.12%	0.87
Entry Rate	1.81%	0.27%	0.58
Exit Rate	0.84%	0.25%	−0.38
Exit Rate: Young Plants	1.68%	0.20%	−0.50

Table 3: Summary Statistics: Model Economy

by the exogenous time-to-deliver entry technology, produces correlations of exit with output and productivity growth which qualitatively (if not quantitatively) mimic those from the U.S. economy. Table 3 reports the mean, standard deviation, and correlation with output growth for several variables from the model economy

By construction, the exit rate's mean and standard deviation are the same in the model and U.S. economies. Its correlation with contemporaneous GDP growth is also nearly identical. Also by construction, the exit rate for young plants has the same mean in the model and U.S. economies, but it is less variable in the model. Its sample standard deviation in the U.S. economy is

1.15%, and in the model economy it is 0.20%. Just as in the U.S. economy, its correlation with GDP growth is larger (in magnitude) than that of the overall exit rate.

The mean entry rate in the model economy is much larger than in the U.S. economy, 1.81% versus 0.62%. The intuition for this is simple: In the model employment is increasing in productivity, and only the least productive plants exit. Entrants are more productive than exiters on average, and there are more of them. Therefore, entrants' employment must be larger than exiters'. The exact opposite is true in the U.S. economy. Incorporating an exogenously increasing productivity process for potential entrants may remedy this. In such a model, the leading edge technology would still determines the entrants' average long run productivity level, but they would begin their lives far below it and exogenously improve in the first few quarters of their lives. Although entrants would still embody all technological progress, they would be hurt by an exogenous, temporary handicap. Therefore, their employment could actually be lower than that of exiters.

Primarily because of the labor supply movements they induce, the shocks to the leading edge technology induce significant fluctuations in output growth. The standard deviation of output growth in the model economy is 0.38%. This implies that the model output growth variance equals 11% of the analogous statistic from the U.S. economy. The model's fluctuations in TFP growth primarily reflect the time-to-deliver investment technology. Following a technological improvement, both exit and the construction of new plants surge. This temporarily moves capital resources from the production sector to the construction sector. When they leave, measured TFP falls, and it rises again when they return. Thereafter, it smoothly rises as the new technology diffuses throughout the economy. By itself, this produces only very small fluctuations in TFP growth. Its standard deviation is only 0.12%. The implied variance is only 2% of its value in the U.S. economy. Possibly, the responses of both output and measured TFP can be amplified by introducing variable capital utilization, as in Greenwood, Hercowitz, and Huffman(1988).

Figures 14, 15,and 16 plot the dynamic correlations of the entry rate, the overall exit rate, and the exit rate for young plants with GDP growth from the model economy. The entry rate is positively correlated with current, future, and lagged output growth. The recession immediately following a technology shock generates a large negative correlation with GDP growth four quarters earlier. The correlations of exit with GDP growth strongly resemble those estimated with the U.S. data. In particular, exit is strongly

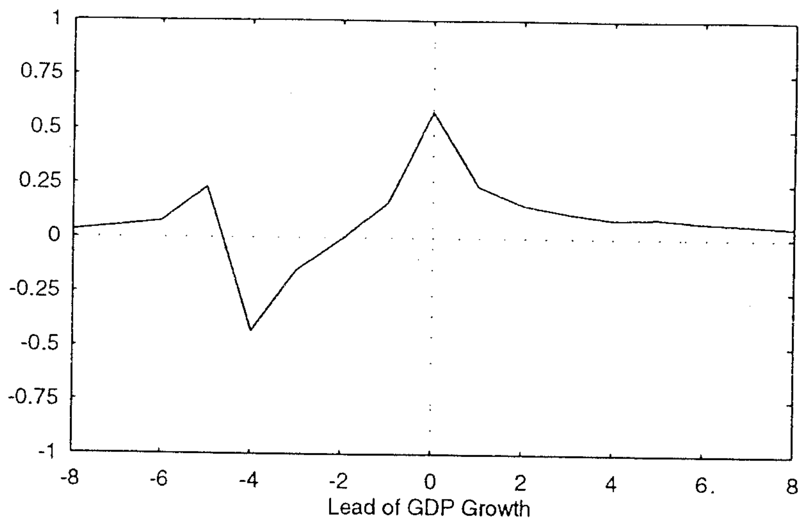

Figure 14: Model's Dynamic Correlations of Entry with ΔGDP

positively correlated with future GDP growth. It also has a smaller positive correlation with GDP growth one quarter ago. The initial positive labor supply response to a shock generates this correlation. As in the U.S. economy, the exit rate of young plants has a similar but weaker relationship. Of course, because the standard deviation of GDP growth in the model is only about one third its estimated value in the U.S. economy, the covariances generated by the model are correspondingly lower. Figure 17 plots the model's dynamic correlations between the exit and entry rates. As in the U.S. economy, the exit rate leads the entry rate by about four quarters. This leading relationship is somewhat stronger in the model than in the U.S. economy. The correlations between the exit rate and the entry rate four quarters hence are 0.48 and 0.26 in the model and are estimated to be 0.23 and 0.30 in the U.S. economy.

Figures 18, 19, and 20 plot the model's dynamic correlations of entry, exit, and the exit of young plants with measured TFP growth. Unsurprisingly, entry is positively correlated with past, current, and future measured TFP growth. As with GDP growth, it is negatively correlated with TFP growth four quarters in the past. The exit rate has a very strong positive correlation with future TFP growth. The correlation between exit and TFP growth four quarters hence is 0.76. One important difference with the U.S. economy is in the contemporaneous relationship between exit and TFP. The sample

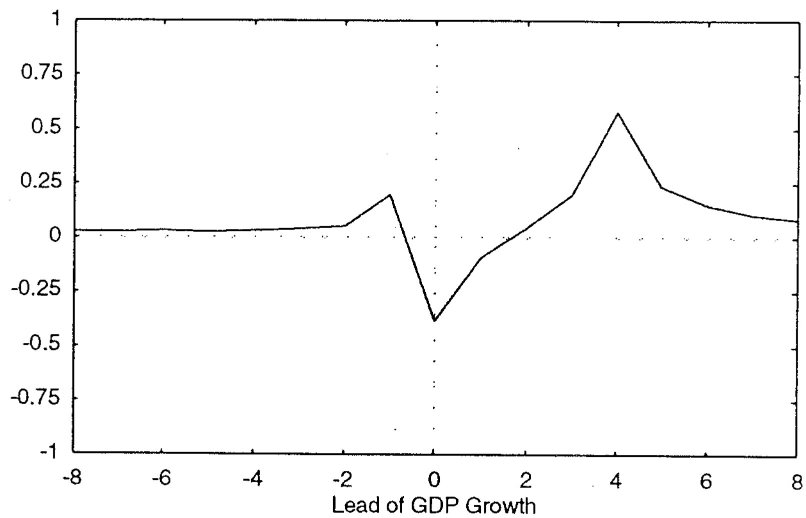

Figure 15: Model's Dynamic Correlations of Exit with ΔGDP

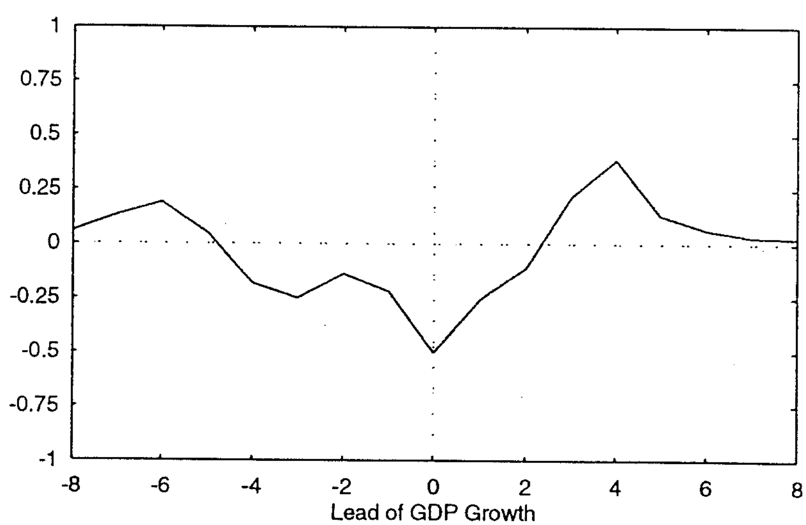

Figure 16: Model's Dynamic Correlations of Young Plant Exit with ΔGDP

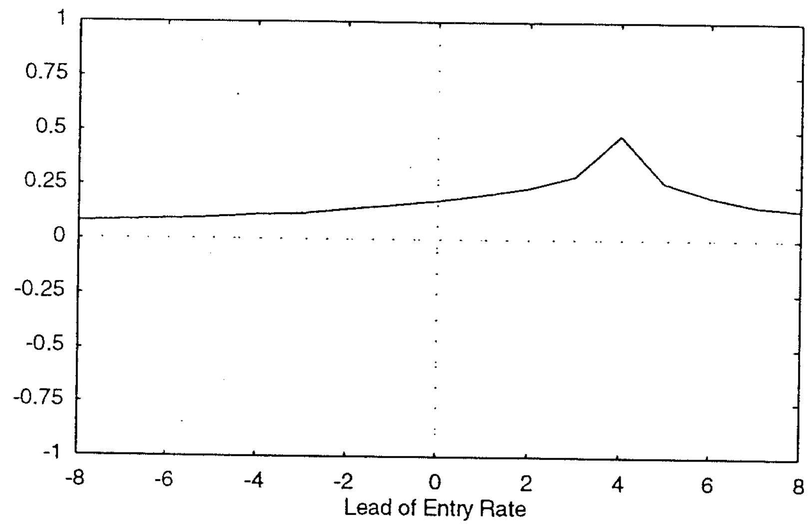

Figure 17: Model's Dynamic Correlations of Exit Rate with Entry Rate.

correlation is nearly zero while in the model it is −0.28. Just as in the U.S. economy, the exit rate for young plants has a similar though weaker relationship with future TFP growth.

6 Conclusion

The pace of a particular kind of resource reallocation, plant entry and exit, has a systematic relationship with the business cycle. The entry rate in manufacturing is moderately procyclical, the exit rate is moderately countercyclical and leads GDP growth, and the exit rate leads the entry rate. A general equilibrium business cycle model in which entry and exit play important roles implementing technological progress mimics this relationship. Shocks to the pace of technological improvement cause all of the model economy's fluctuations. As in Greenwood, Hercowitz, and Huffman(1988), they affect output in the short run primarily through labor supply. Over a longer horizon, a technological improvement expands the economy's production possibilities as it diffuses through the production sector. This long run impact of a technology shock drives exit's short run behavior. The decision to close

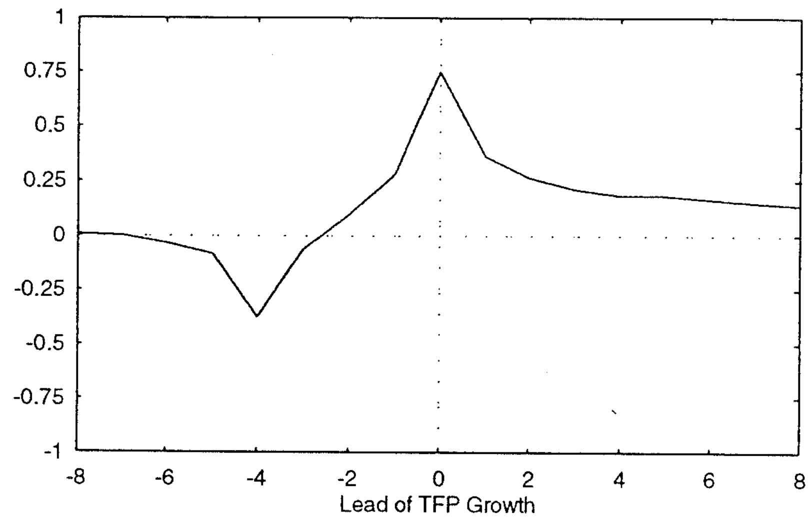

Figure 18: Model's Dynamic Correlations of Entry with ΔTFP

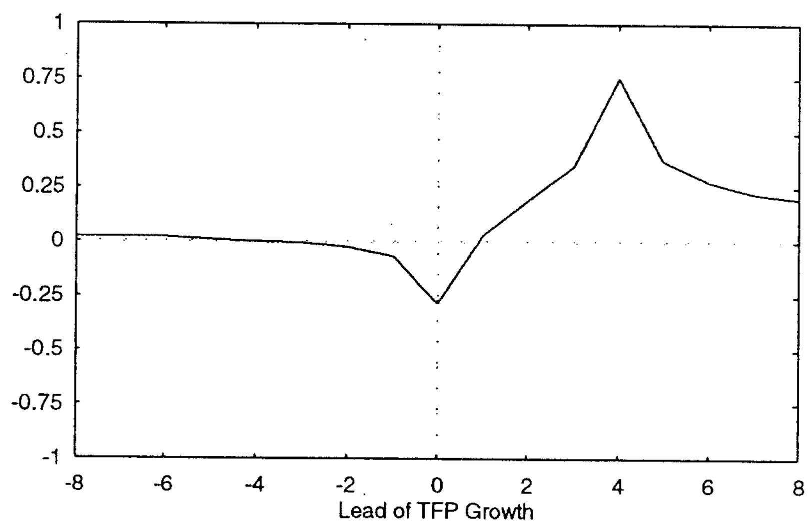

Figure 19: Model's Dynamic Correlations of Exit with ΔTFP

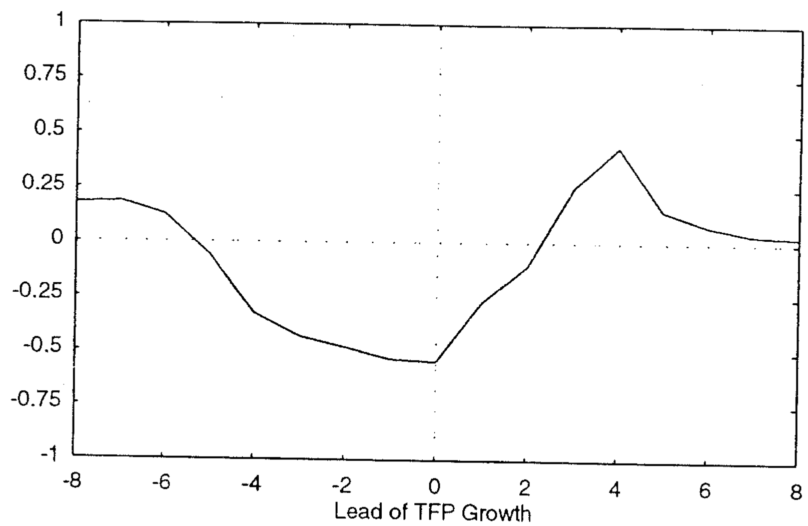

Figure 20: Model's Dynamic Correlations of Young Plant Exit with ΔTFP

a plant is irreversible, and a plant's productivity is subject to ongoing uncertainty. As Dixit and Pindyck(1994) note, this will cause a delay in exit relative to a situation with no uncertainty or reversibility. Active plants on the margin of exit only remain to see whether their fortunes will improve or not. An improvement to the leading edge technology lowers the value of existing plants because they can not implement it. Therefore exit rises immediately after a technological improvement, long before it is actually implemented. Concurrently, construction on a new wave of entrants begins. The start of their activity begins the implementation of the new technology, beginning a long run expansion. Incorporating microeconomic realism, ongoing uncertainty at the plant level, into the model economy influences its characterization of entry and exit in a way which matches observation. This success suggests that further study of plant level dynamics can shed light on important macroeconomic issues.

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