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Sunk Entry Costs, Sunk Depreciation Costs, and Industry Dynamics

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Abstract: Dynamic competitive models of industry evolution predict higher variability of firm value over time and lower variability of firm activity over time in industries where sunk entry costs are higher. These predictions have done well empirically. Here we extend the theory to allow an additional category of sunk costs---depreciation---and argue that this generates countervailing effects. We test this assertion empirically and find the results are consistent with the theory.

Keywords: Sunk costs, depreciation, entry.

JEL Classification: L00

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1. Introduction

There is a substantial literature on competitive industry dynamics. This literature includes both theoretical and empirical contributions, and these complement each other nicely.[1] Two robust predictions of the theory are: (1) a positive relationship between sunk entry costs and the intertemporal variability of firm value, and (2) a negative relationship between sunk entry costs and the intertemporal variability of the number of firms. The first prediction arises from natural equilibrium conditions requiring that firm values be at most equal to entry costs (because higher values provoke entry) and at least equal to scrap value (because lower values provoke exit). This suggests that the range of firm value over time should be approximately equal to the difference between the entry cost and the scrap value, which in turn is a natural definition of sunk entry cost. It follows almost immediately that the range of firm value over time is equal to, and hence increasing in, the sunk entry cost. The second prediction arises because higher sunk entry costs make entry and exit more expensive and so tend to reduce the variability in the number of active firms over time. Although detailed data on sunk entry costs do not seem to be available, these predictions have been tested using various proxies and found to be consistent with the data.

This paper extends the analysis by introducing depreciation, a category of sunk cost that has not received much attention in this corner of the literature.[2] It turns out that sunk

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[1] Examples of empirical work include Deutsch (1984), Dunne, Roberts and Samuelson (1989), Geroski, Gilbert, and Jacquemin (1990), Geroski and Schwalbach (1991), Siegfried and Evans (1992,1994), Audretsch (1995), Lambson and Jensen (1995,1998), Gschwandtner and Lambson (2002,2006), Disney, Haskel, and Heden (2003), and many others. Examples of theoretical work include Jovanovic (1982), Ericson and Pakes (1989), Dixit (1989), Sutton (1991), Lambson (1991,1992), Hopenhayn (1992), Cabral (1995), Caballero and Pindyck (1996), and many others.

[2] There are, of course, exceptions. See, for example, Kessides (1990), Farinas and Ruano (2005), and Vivek (2007).

depreciation costs behave differently than sunk entry costs; indeed, they dampen the effects of the latter. For intuition, consider the extreme case in which firms' assets completely depreciate each time period. Then when entry and exit decisions are made at the beginning of the subsequent period, the active firms have no advantage over potential entrants. In equilibrium, entry and exit maintain firm value equal to the entry cost. Thus, in contrast to high sunk entry costs, which are associated with high intertemporal variability of firm value and low intertemporal variability of the number of firms, high depreciation generates low intertemporal variability of firm value and high intertemporal variability of the number of active firms.

Section 2 spells out the theoretical arguments upon which these empirical implications rest. Section 3 describes the measurement of depreciation. It gathers market-based (not accounting-based) estimates of depreciation rates for various capital inputs from the existing literature and explains how we incorporate those into the subsequent empirical analysis. Section 4 presents the empirical results, which are consistent with the theory. Section 5 concludes.

2. Entry costs and depreciation rates: theory

2a. Value of firms

In the absence of depreciation, the theoretical result that the variability of firm value over time is positively correlated with sunk entry cost is robust in that very little structure is required to demonstrate it. Specifically, let ξ be the cost of creating a firm and let χ be the value of scrapping a firm. Natural equilibrium conditions require that firm value, V, be bounded above by ξ (because higher values provoke entry and thus cannot persist) and bounded below by χ (because lower values provoke exit and thus cannot persist). If market conditions are variable enough and the observation time long enough for V to visit each end of its support, then the range of V over time is $\xi - \chi$. Since this is a plausible definition of sunk entry cost, the range of firm value is identical to, and hence positively correlated with, the sunk entry cost.[3]

Depreciation, the loss of value sunk through wear and tear on or consumption of capital inputs, differs from the loss of value that is sunk when productive capacity is newly committed to an industry. Let ξ_i denote the number of units of input i required to enter an industry, where the units of each input have been normalized to have a price of one. Further suppose that each period a fraction λ_i of input i fails and must be replaced in order for production to continue. Instead of continuing, the firm may be scrapped and the scrap value of each input, χ_i, may be recouped. Potential entrants compare the cost of entry, $\xi = \sum_i \xi_i$, with their value if they enter. Thus entry has a tendency to place an upper bound on a firm's value that is equal to the entry cost. Similarly, active firms compare their value if they remain active with their value if they exit. The latter includes the avoidance of the depreciation costs that must be paid to continue activity---namely $\sum_i \lambda_i \xi_i$ ---as well as the scrap value of the firm, $\chi = \sum_i \chi_i$. Thus a firm's value cannot dip below $\sum_i \lambda_i \xi_i + \sum_i \chi_i$ without provoking exit. This suggests that firm value over time is trapped between $\sum_i \xi_i$ above and $\sum_i \lambda_i \xi_i + \sum_i \chi_i$ below. If the market conditions are variable enough and the observation time is long enough for firm value to visit the extreme points of its support, then the range of firm value over time is

$$R = [\sum_i \xi_i - \sum_i \chi_i] - \sum_i \lambda_i \xi_i. \quad (2.1)$$

Inspection reveals that the range of firm value depends positively on sunk entry costs as before, but depends negatively on sunk depreciation costs.

[3] See Lambson (1992). The empirical importance of sunk entry costs in various contexts has been studied by Asplund (2000), Ramey and Shapiro (2001) and others.

2b. Number of active firms

Economic intuition suggests that higher sunk entry costs, by raising the cost of entry and exit, will tend to reduce the level of such activities. Although this result is not as straightforward as the effects of sunk costs on the variability of firm value, it is broadly true. Lambson (1992) showed that if the sunk entry cost, $\sum_i \xi_i - \sum_i \chi_i$, is increased either by increasing the entry cost $\sum_i \xi_i$ or decreasing the scrap value $\sum_i \chi_i$ then the range of the number of active firms is negatively related to sunk entry costs. A similar argument with depreciation establishes that the range of the number of active firms is negatively related to $\sum_i \xi_i - (\sum_i \lambda_i \xi_i + \sum_i \chi_i)$ when it is increased either by increasing $\sum_i \xi_i$ with $(\sum_i \lambda_i \xi_i + \sum_i \chi_i)$ fixed or by decreasing $(\sum_i \lambda_i \xi_i + \sum_i \chi_i)$ with $\sum_i \xi_i$ fixed. This doesn't imply that the range of the number of active firms is decreasing in sunk entry costs, although it is suggestive. It does imply, however, that the range of the number of active firms is increasing in sunk depreciation costs.

To illustrate, suppose there is only one input required for entry, and there are two market conditions, one with high demand and another with low demand. The distribution is i.i.d. with ρ the probability of the high demand condition. Suppose that changes in demand are large, so that whenever the market condition improves there is entry and whenever it deteriorates there is exit. Then the indifference relations for entry and exit are:

(2.2) $$\pi (y^h,h) + \beta[\rho\xi + (1-\rho)\chi] = \xi$$

(2.3) $$\pi (y^l,l) - \lambda\xi + \beta[\rho\xi + (1-\rho)\chi] = \chi$$

where β is the discount factor, y^h is the number of active firms when demand is high, y^l is the number of active firms when demand is low, and π is the one-period profit of an active firm. Subtracting the second equation from the first yields:

$$(2.4) \qquad \pi(y^h,h) - \pi(y^l,l) = (\xi - \chi) - \lambda\xi.$$

Equation (2.4) exhibits a range of firm profits that is increasing in the sunk entry cost and decreasing in the sunk depreciation costs. Now if, for example, $\pi(y,m) = (\alpha_m - y)$ then (2.4) becomes:

$$(2.5) \qquad (y^h - y^l) = (\alpha_h - \alpha_l) - (\xi - \chi) + \lambda\xi$$

so the range of the number of firms is decreasing in the sunk entry cost and increasing in the sunk depreciation costs.

3. Measuring depreciation

Jorgensen (1996) and Fraumeni (1997) discuss the empirical literature on depreciation. We share with them the view that economically relevant measures of depreciation are determined by the workings of resale markets for capital assets. Such measures are more likely to be economically relevant than, for example, accounting measures.

We require two different measures of depreciation: a firm-level measure to test the implications of Section 2a and an industry-level measure to test the implications of Section 2b. To construct either measure requires an estimate of depreciation for each capital input. We have taken these from Hulten and Wykoff (1981) as summarized by Jorgenson (1996) Table II. Hulten and Wykoff apply the Box–Cox power transformation to used asset prices in order to estimate the rate and form of economic depreciation. This allows them to statistically discriminate between various patterns of depreciation (most importantly, geometric, linear and ‘one-hoss-shay’ depreciation patterns). They find that the observed depreciation patterns are approximately geometric. In a later paper Hulten and Wykoff (1996) revised and extended these measures to include the effect of obsolescence, defined as the decline in price resulting from the introduction of new vintages of capital. As a result the revised rates are generally somewhat higher than the initial Hulten-Wykoff depreciation rates. These two sets of depreciation estimates will be referred to as HW1 and HW2, respectively. Finally, the Bureau of Economic Analysis (BEA) published its own estimates of depreciation rates for use in the National Income and Product Accounts. The estimates employed in the national accounts differ from the other two depreciation measures in that they incorporate information about lifetimes and salvage values of assets and accounting formulas permitted for tax purposes. The economic depreciation rates for nonresidential structures estimated by Hulten and Wykoff are much lower than those employed in the U.S. national accounts. The BEA depreciation rates can be found, for example, in Jorgenson and Sullivan (1981). More recent but not very different depreciation rates can be found in Fraumeni (1997). Despite the differences in construction, our results using the BEA depreciation rates do not differ significantly from the results using the two Hulten-Wykoff estimates.

We constructed the firm-level estimate of depreciation as a weighted sum of the depreciation rates of the capital inputs used by the firm. The weights are estimates of the firm's expenditures for the respective capital inputs. Specifically, the depreciation index for firm f in industry F is

$$(3.1) \qquad \boldsymbol{\Lambda_f = \sum_I} \lambda_i P_{iF} (S_f/S_F),$$

where S_f is firm *f's* average sales over time, λ_i is the depreciation rate of input i, P_{iF} is the aggregate expenditure on input i in industry F, and S_F is industry F's average sales over time. For the industry's expenditures on input i, P_{iF}, we used the capital flows table constructed by the Industry Economics Division (IED) of the Bureau of Economic Analysis (BEA) of the United States Department of Commerce. The capital flows table is a supplement to the benchmark input-output accounts and it shows purchases of new structures, equipment and software by industry. Specifically, the capital flows table lists the capital inputs used in each industry; these were multiplied by the depreciation rates for the respective industries in which the inputs were produced and summed.

We used similar methods to construct our depreciation measures for the analysis of the intertemporal number of firms in an industry. In contrast to the analysis of intemporal firm value, where each observation corresponds to a firm, here an observation corresponds to an industry. Of course, defining industries is seldom without difficulties. We assigned firms to industries according to SIC (NAICS) codes at the 2-4 digit level. It is well known that this approach is not perfect—for example, since many of the firms are diversified across product lines they might not be well described by a single SIC code—but we have no compelling reason to believe that these shortcomings introduce any biases. If expenditures per unit of output (sales) is interpreted as a cost of capacity, then

$$\Lambda_F = \sum_I \lambda_i P_{iF} / S_F \qquad (3.2)$$

is interpretable as the depreciation rate of capacity in industry F.

Finally, we emphasize again that these depreciation measures are based on market prices. These are more likely to reflect the economically relevant depreciation rates than are estimates that follow accounting rules that are not necessarily correlated with economic activity. Furthermore, the functional forms used to determine the depreciation rates are very flexible and therefore much more probable to approximate the real pattern of depreciation than typical accounting rules.

4. Entry costs and depreciation rates: evidence

4a. Value of firms

The regressions in this subsection test the proposition from Section 2a that the range of firm value depends negatively on the rate of depreciation of its capital inputs. We also control for the size of the sunk entry costs, as is suggested by the existing literature. The database used for these purposes contains information on 162 companies. All of them are publicly traded manufacturing companies in the United States observed between 1950 and 2001. The sample is comprised of those firms among the largest 500 companies (in terms of sales) as of 1950 for which a complete time series on profits for the analyzed period existed. There is obvious selection bias in the firms that survive, but it is irrelevant because the theory makes predictions about surviving firms. Most of the database was compiled from Standard and Poor's Compustat. Gaps—mostly a problem in the early years—were filled from Moody's Industrial Manual.

We regress firm value variability on measures of sunk depreciation costs and sunk entry costs. As is commonly done, we measure firm value as the sum of stock market capitalization and total liabilities. Stock market capitalization is calculated as the year-end closing price of common shares times the number of common shares outstanding. The closing price is the closing trade price for shares traded on a national stock exchange and the closing bid price for shares trading over-the-counter. We measured intertemporal variability in two usual ways: range and variance. Although theory favors range as the appropriate measure, variance is less sensitive to data problems that result in outliers. It turns out that one may remain agnostic as to which is the better measure: the regressions with range and the regressions with variance yield similar results.

The results of these regressions are in Appendix A. One star denotes significance at the 10% level or better, two stars denote significance at the 5% level or better, and three stars denote significance at the 1% level or better. The equations include both a sunk entry cost proxy as in prior studies (namely, investment in property, plants and equipment) and a sunk depreciation cost. Various dependent variables are considered: range, variance, log of range, log of variance. The coefficient of the sunk entry cost proxy is positive, as predicted. The coefficient of the sunk depreciation cost is negative, as predicted. Concerned that fifty years might be too long to expect a firm to remain similar, we also divided the 50 years of the sample into ten year subsamples. Our conclusions were unaffected. In addition to what we have reported, we tried several other robustness checks, including the number of employees, capital expenditures, capital intensiveness (as measured by the capital-labor ratio), and new capital expenditures. None of these variants had any significant effect on our results.

4b. Number of firms

To explore the relationship between the variability of firm activity and sunk entry and depreciation costs, we used annual data from the US Census Bureau. With sponsorship from the US Small Business Administration (SBA), the Census Bureau collects data on entry and exit by industry for the United States as a whole and for each state.[4] This database contains information about entry, exit, and employment from 1990-2000 for each included industry.[5]

The theory asserts that the range of the number of active firms over time should be positively related to sunk depreciation costs. (The effect of sunk entry costs is murkier, and indeed the entry cost proxy does not achieve a statistically significant coefficient.) Our data do not include the number of firms. They do include annual data on entry and exit. Fortunately, this is adequate to calculate the range of the number of firms because, assuming there is enough variability over time and a long enough observation period to observe the extremes, the range of the number of firms is

$$R(y) = \max_\tau \{y_o + \textstyle\sum_{t=1}^{\tau} [n_t - x_t]\} - \min_\tau \{y_o + \textstyle\sum_{t=1}^{\tau} [n_t - x_t]\}$$

$$= \max_\tau \{ \textstyle\sum_{t=1}^{\tau} [n_t - x_t]\} - \min_\tau \{ \textstyle\sum_{t=1}^{\tau} [n_t - x_t]\}.$$

Since the initial number of firms, y_o, cancels, not observing it poses no problem.

The results are reported in Appendix B. The various specifications all exhibit significant coefficients of the predicted sign for depreciation.

5. Concluding Remarks

The field of industrial organization began as the study of imperfect competition. Differences in profit rates across industries, a very well documented phenomenon, were taken to be evidence that competition was imperfect. However, differing profit rates across

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[4] These data are available at: http://www.sba.gov/advo/stats/data.html.

[5] More specific information is at: http://www.census.gov/csd/susb/susb2.htm#godyn1 .

industries are consistent with perfect competition, even in the long run. (See Lambson (1992).) Since maximizing average profits is not the firms' objective, the market provides no mechanism to equalize them. Rather, if firms attempt to maximize the expected present value of investments, then it is the value of a marginal dollar of investment that will tend to equalize across investments. Under these circumstances, it seems likely that any robust empirical implications will be inherently dynamic. This paper has focused on a few of these dynamic implications, showing them to be consistent with the data.

Appendix A

A.1: Dependent variable is the logarithm of the range of firm values

Intercept	HW1	HW2	BEA	Entry	Adj.R²	Obs
8.74 (0.184)***	-3.34 (0.803) ***			0.21 (0.099)**	0.12	162
8.74 (0.185)***		-3.43 (0.812)***		0.21 (0.099)**	0.12	162
8.69 (0.184)***			-4.40 (0.950)***	0.21 (0.10)**	0.14	162

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment. Sunk is the average per firm over the period 1950-2001.

A.2: Dependent variable is the logarithm of the variance of firm values

Intercept	HW1	HW2	BEA	Entry	Adj.R²	Obs
14.98 (0.371)***	-6.53 (1.61) ***			0.42 (0.198)**	0.11	162
14.96 (0.37)***		-6.71 (1.63)***		0.42 (0.198)**	0.11	162
14.88 (0.370)***			-8.61 (1.91)***	0.42 (0.196)**	0.12	162

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment. Sunk is the average per firm over the period 1950-2001.

A.3: Dependent variable is the logarithm of the range of firm values within decades

Intercept	Ln(HW1)	Ln(HW2)	Ln(BEA)	Ln(Entry)	Adj.R^2	Obs
6.221 (0.582)***	-0.294 (0.07) ***			0.803 (0.088)***	0.52	803
6.197 (0.586)***		-0.291 (0.071)***		0.806 (0.891)***	0.52	803
6.121 (0.572)***			-0.283 (0.692)***	0.813 (0.087)***	0.52	803

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment. Entryk is the average per firm over the decades. Numbers in parentheses are robust standard errors cluster corrected by industry.

A4: Dependent variable is the logarithm of the variance of firm values within decades

Intercept	Ln(HW1)	Ln(HW2)	Ln(BEA)	Ln(Entry)	Adj.R^2	Obs
10.558 (1.177)***	-0.610 (0.142) ***			1.559 (0.178)***	0.52	803
10.51 (1.186)***		-0.604 (0.143)***		1.564 (0.180)***	0.52	803
10.370 (1.156)***			-0.587 (0.140)***	1.579 (0.175)***	0.52	803

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment.

A.5 Dependent variable is the logarithm of the range of firm values within decades

Intercept	Ln(HW1)	Ln(HW2)	Ln(BEA)	LN(Entry)	Ln(L)	Adj.R²	Obs
6.025 (0.576)***	-0.224 (0.071) ***			0.699 (0.082)***	0.001 (0.000)***	0.57	803
6.000 (0.578)***		-0.221 (0.071)***		0.702 (0.082)***	0.000 (0.000)***	0.57	803
5.958 (0.569)***			-0.216 (0.069)***	0.706 (0.08)***	0.000 (0.000)***	0.57	803

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment. Ln(L) is the logarithm of the number of employees. Sunk and L are the averages per firm over the decades. Numbers in parentheses are robust standard errors cluster corrected by industry.

A6: Dependent variable is logarithm of the variance of firm values within decades

Intercept	Ln(HW1)	Ln(HW2)	Ln(BEA)	Ln(Entry)	Ln(L)	Adj.R²	Obs
10.17 (1.163)***	-0.471 (0.142) ***			1.352 (0.165)***	0.001 (0.000)***	0.57	803
10.12 (1.167)***		-0.465 (0.143)***		1.357 (0.166)***	0.000 (0.000)***	0.57	803
10.026 (1.148)***			-0.454 (0.141)***	1.367 (0.162)***	0.000 (0.000)***	0.57	803

Note: HW1, HW2 and BEA denote the depreciation index calculated from (3.1) for the various data sources. Entry refers to Investment in property plant and equipment. LnL is the logarithm of the number of employees. Sunk and L are the averages per firm over the decades. Numbers in parentheses are robust standard errors cluster corrected by industry.

Appendix B: Intertemporal number of firms

Dependent variables: Logarithm of the Range of the Number of Active Firms

Eq.	Ln(HW1)	Ln(IRB)	Ln(BEA)	Ln(K/L)	Ln(NewK/L)	Adj.R^2
1	0.466 (0.223)**			0.144 (0.249)		0.12
2		0.479 (0.22)**		0.136 (0.248)		0.12
3			0.403 (0.23)**	0.161 (0.257)		0.10
4	0.468 (0.223)**				0.137 (0.245)	0.12
5		0.482 (0.22)**			0.130 (0.244)	0.13
6			0.405 (0.23)*		0.161 (0.257)	0.010

Note: Numbers in parenthesis are White-Huber corrected root square errors. $I_b=[\sum\lambda_i P_{ib}]/V_b$ where i indexes inputs in the industry, V_b denotes the value of shipments of the industry in 1992. IRb is the index using the revised depreciation rates. IRBEAb is the index using the BEA depreciation rates. K/L=Capital Expenditures/Employees, NewK/L= New Capital Expenditures/Employees. The number of industries is 61.

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