Business Fixed Investment and the Structure of Adjustment Costs

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This paper empirically tests an irreversible investment model against the standard convex adjustment cost model using panel data from COMPUSAT. It shows that the reduced form of the optimal irreversible investment decision turns out to be a Tobit model with measurement errors in the dependent variable. Our non-nested test indicates that the evidence for the irreversible investment model is weak: Only 5 firms among our total sample of 56 firms strictly prefer the irreversibility specification. (*JEL* classification: E20)

I. Introduction

The purpose of this paper is to empirically evaluate competing theories of business fixed investment using panel data from COMPUSTAT. The theories evaluated differ in the form of the costs incurred when the capital stock is adjusted. Specifically, two competing hypotheses about adjustment costs and investment dynamics are tested: One based on standard convex adjustment costs and the other based on linear kinked adjustment costs, which includes irreversibility of investment as an extreme case.

With convex costs of adjustment, profit maximizing firms adjust their capital stock frequently and in small increments in response to changes in their economic environment. As was shown by Eisner and Strotz (1963) and Lucas (1967), convex costs can provide a theoretical foundation for the use of distributed lags in the econometric

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investigation of investment equations.[1] They have also been shown to provide a rigorous foundation for Tobin's q theory of investment.[2]

However, in view of the popularity of distributed lag and q models in the empirical literature, the arguments for convex costs are quite weak. Generally, the convexity of adjustment costs is attributed to a combination of increasing prices in factor markets and increasing unit costs of installation as the rates of investment increase. As noted by Rothschild (1971), the first effect is not important for relatively small firms and the second effect is only likely to exist at very high rates of investment. At usual rates, it is conceivable that adjustment cost functions are linear or concave due to indivisibilities and the use of information as an input in the installation process. As the firm's optimal investment program and the implied investment dynamics critically depend on the assumed form of the adjustment cost function, non-convexities of adjustment costs should be seriously considered.

When the convexity assumption is abandoned, it has been shown that optimal capital adjustment is less frequent and more lumpy than under convexity.[3] For example, in the presence of the two sided linear adjustment costs, the firm's optimal policy is to set investment to zero as long as the marginal productivity of capital remains within certain barriers, and to adjust to the desirable level at once if the marginal productivity of capital crosses either barrier.[4]

It is clear from the above discussion that theoretical considerations alone cannot help us decide which form of adjustment costs is more realistic, and that we need to turn to the empirical evidence. Several authors have conducted empirical studies of models with non-convex adjustment costs, but as far as we know, they are all models of either consumer durables or labor demand.[5]

[1]Chenery (1952) and Hall and Jorgenson (1967) are early examples of the distributed lags approach to estimating investment equations.

[2]See, for example, Lucas and Prescott (1971), Hayashi (1982), and Abel (1983).

[3]Bertola and Caballero (1990) has a brief literature survey for the models with non-convex adjustment costs.

[4]The irreversibility of new investment can be viewed as an extreme case of the linear kinked adjustment cost model by making the cost per unit of disinvestment larger than the present discounted value of the per unit user cost of capital. In that case, it is never profitable to disinvest. The optimal investment policy is similar to the one just described but without the lower barrier.

This, perhaps, reflects the belief that since we do not observe many zeros in investment series, and since series of aggregate investment are relatively smooth, one does not even need to test lumpy investment models.

There are several reasons why this argument may not be true. First, consider the case of heterogeneity of capital stocks. Suppose capital specific cost shocks cause different capital stocks to adjust at different times. In that case, when aggregated at the firm level, observed total investment would be positive even if investment in some types of capital stocks is zero. Second, if the capital stock is homogeneous and adjustment costs are incurred on net rather than gross investment, then we should be looking for zeros in net investment series, and it is no longer clear whether we observe many zeros or not.[6] Also, even if aggregate investment series are smooth, it does not follow that investment at the firm level is smooth since the timing of lumpy adjustments can be sufficiently staggered across firms.[7] This suggests that it is important to test non-convex investment models at a disaggregated level. Testing at a disaggregated level also avoids introducing auxiliary assumptions needed to solve aggregation problems. (See Bertola and Caballero 1990)

This paper empirically tests an irreversible investment model against two models of convex adjustment costs using firm level data. Under the assumption that capital is homogeneous and irreversible, the derived reduced form of the irreversible investment model turns out to be a Tobit model with measurement errors in the dependent variable. This can be easily understood since we would expect to see some zeros in net investment. Our empirical results indicate that the evidence for the irreversible investment model is weak: Even though we found that 5 out of 18 small firms strictly prefer the irreversibility specification, these were the only 5

[5]Lam (1989), Caballero (1990, 1991), and Eberly (1991) test lumpy adjustment of consumer durables. Hammermesh (1989) and Bentolila and Bertola (1990) empirically examine lumpy adjustment of labor demand.

[6]Pindyck and Rotemberg (1983) give some empirical evidence that adjustment costs are incurred on net investment.

[7]Rhee and Rhee (1991) suggested this point as a possible explanation for their finding that the slow adjustment model performs fairly well with aggregated micro data from COMPUSTAT but very poorly at the individual firm level.

firms among our total sample of 56 firms to do so. A possible objection to this finding is that the assumption of homogeneity of capital is too restrictive against the irreversible investment specification. If capital is heterogeneous, it is no longer necessary to observe zeros in investment series under the irreversibility specification. The case for heterogeneous capital stocks and thereby the aggregation problem are unanswered in this paper and left for the future research.

The rest of this paper is organized as follows. Section II presents the irreversible investment model with a homogeneous capital stock. Section III explains estimation procedures for the investment equations derived in Section II. The empirical evidence and non-nested hypothesis tests are contained in Section IV. Section V concludes and contains a discussion of future extensions.

II. An Irreversible Investment Model with Homogeneous Capital

In this section, we briefly present a model of irreversible investment adapted from Bertola and Caballero (1990). Our description will highlight the main equations and conclusions necessary for our econometric specification.[8] Assume that the firm produces a homogeneous good by a constant elasticity production function

$$Y(t)=K(t)^{\gamma}\cdot\varepsilon_s(t), \tag{1}$$

and faces a constant elasticity demand function for its product given by

$$P(t)=Y(t)^{-\eta}\cdot\varepsilon_d(t). \tag{2}$$

$\varepsilon_s(t)$ and $\varepsilon_d(t)$ are sources of uncertainty in the model and are assumed to follow geometric Brownian motions. The firm can increase its capital stock by paying per unit price $w(t)$ which may include linear installation costs. Under the above specification, the firm's revenue, $\Pi(K(t), Z(t))$, can be written as

[8]Our setting differs from theirs in that net, rather than gross, investment is always non-negative. This implicitly assumes that depreciation expenditures are essential for the operation of any capital, as well as the usual assumption that it never pays to re-sell installed capital.

$$\Pi(K(t),\ Z(t)) \equiv P(t)\cdot Y(t) = K(t)^{\alpha}\cdot Z(t), \tag{3}$$

where $\alpha \equiv \gamma(1-\eta)$ and $Z(t) \equiv \varepsilon_s(t)^{1-\eta}\cdot \varepsilon_d(t)$. The variable $Z(t)$ is an index of business conditions at every instant. Since $\{Z(t)\}$ is a constant-elasticity function of $\varepsilon_s(t)$ and $\varepsilon_d(t)$, it also follows a geometric Brownian motion. The firm's objective is to maximize the expected present discounted value of cash flows;

$$V(K(t),\ Z(t),\ P(t))$$
$$= \max_{\{I(t)\}} E_t\left\{ \int_t^{\infty} e^{-\rho(t'-t)}[\Pi(K(t'),\ Z(t')) - W(t')(I(t') - \delta\cdot K(t))]dt' \right\} \tag{4}$$
$$\text{subject to } dK(t) = [I(t) - \delta\cdot K(t)]dt,$$
$$\text{and } I(t) - \delta\cdot K(t) \geq 0,\ \forall t.$$

Define a "desired" capital stock, $K^d(P(t),\ Z(t))$, as the optimal capital stock of the above program when the irreversibility constraint is *not binding*.[9] With the specific functional forms assumed in this model, $K^d(t)$ can be shown to be proportional to the optimal capital stock *without the irreversibility constraint*, $K^f(t)$ (the frictionless capital stock). $K^f(t)$, in turn, is a log linear function of the shocks $\varepsilon_s(t)$ and $\varepsilon_d(t)$, as well as the interest rate $r_k(t)$ which represents the cost of capital. From the definition of $K^d(t)$, the dynamics of investment can be characterized by

$$K_t^d(P(t),\ Z(t)) \leq K_t\ \ \forall t, \tag{5}$$

$$K_t^d(P(t),\ Z(t)) = K_t, \qquad \text{if } I(t) - \delta\cdot K(t) > 0, \tag{6}$$

$$\log K^d(t) = c + \frac{1}{1-\alpha}(\log Y(t) - \log r_k(t)) + \frac{\alpha}{1-\alpha}\log K(t). \tag{7}$$

Equation (7) is obtained by recovering the unobservable shocks, ε_s and ε_d, from equations (1) and (2) respectively.

A discrete time version of equations (5) through (7) can be written as;[10]

$$\begin{cases} I_t - \delta\cdot K_{t-1} = K_t^d - K_{t-1}, & \text{if } (1-\delta)K_{t-1} < K_t^d, \quad (8) \\ I_t - \delta\cdot K_{t-1} = 0 & \text{if } (1-\delta)K_{t-1} \geq K_t^d, \quad (9) \\ \log K_t^d = E(a_0 + a_1\log Y_t + a_2\log K_t + a_3\log r_k \mid \Omega_t). & (10) \end{cases}$$

[9] $K^d(P(t),\ Z(t))$ is the capital stock associated with the fixed upper barrier on the marginal revenue product of capital.

[10] We use subscript t to differentiate the discrete time model from the continuous time model.

In (10), we assume that managers do not have information on current shocks. In that case, the desired capital stock will depend on the expectation of the current shocks given the manager's information set Ω_t.[11]

III. Econometric Issues

For our empirical work, we first transform the system (8)-(10) by taking logs,

$$\begin{cases} \log\left\{\dfrac{I_t-\delta K_{t-1}}{K_{t-1}}+1\right\} \cong \dfrac{I_t-\delta K_{t-1}}{K_{t-1}} = \log K_t^d - \log K_{t-1}, \text{ if}(1-\delta)K_{t-1}<K_t^d & (11) \\ \dfrac{I_t-\delta K_{t-1}}{K_{t-1}} = 0 \qquad \text{if } (1-\delta)K_{t-1}\geq K_t^d, & (12) \\ \log K_t^d/K_{t-1} = E(a_0+a_1\log\left(\dfrac{Y_t}{K_{t-1}}\right)+a_2\log\left(\dfrac{K_t}{K_{t-1}}\right)+a_3\log r_k \mid \Omega_t). & (13) \end{cases}$$

Introducing measurement errors, the system (11)-(13) can be compactly written as

$$\frac{I_t-\delta K_{t-1}}{K_{t-1}} = \begin{bmatrix} \alpha E(Z_t|\Omega_t)+\eta_t, & \text{if } E(Z_t|\Omega_t)>0 \\ \eta_t, & \text{if } E(Z_t|\Omega_t)<0 \end{bmatrix}$$

$$= 1[\alpha E(Z_t|\Omega_t)>0]\cdot \alpha E(Z_t|\Omega_t)+\eta_t, \qquad (14)$$

$$Z_t = \beta\cdot Z_{t-1} + V_t, \qquad (15)$$

where Z_t is a vector of observables in logs which determines the desired capital stock minus the previous period's capital stock as in (13), α is a vector of unknown coefficients, $1[\cdot]$ is an index function, η_t is measurement error, and Ω_t denotes the information set of manager. Z_t is assumed to follow a vector autoregressive process as in (15).[12]

Assume that the econometrician has the information set, ψ_t, which is a subset of the manager's information set Ω_t, and $Z_{t-1}\in\psi_t$.

[11]We would like to note that the above derivations would go through with more general two sided non-convex adjustment costs using the techniques in Bentolila and Bertola (1990), Grossman and Laroque (1990), or Dixit (1991). In that case, the optimal policy specifies two reflecting and two returning barriers for the marginal revenue product of capital.

[12]The assumption that Z_t follows a first order process is not restrictive since the autoregression in (22) could be the companion form of a higher order VAR.

Define ε_t as a $N(0, \sigma_1^2)$ forecast error due to the difference between information sets, i.e.,

$$\varepsilon_t = \alpha E(Z_t \mid \Omega_t) - \alpha E(Z_t \mid \psi_t). \tag{16}$$

By combining (14), (15), and (16), the system can be rewritten as,

$$\begin{aligned} \frac{I_t - \delta K_{t-1}}{K_{t-1}} &= 1[\alpha E(Z_t \mid \Omega_t) > 0] \cdot \alpha E(Z_t \mid \Omega_t) + \eta_t \\ &= 1[\varepsilon_t > -\alpha\beta Z_{t-1}] \cdot (\alpha\beta Z_{t-1} + \varepsilon_t) + \eta_t \\ &= 1[\varepsilon_t > -\gamma Z_{t-1}] \cdot (\gamma Z_{t-1} + \varepsilon_t) + \eta_t, \end{aligned} \tag{17}$$

where $\gamma \equiv \alpha\beta$.

Now, take the expectation of (17) conditional on ψ_t, then

$$\begin{aligned} E\left(\frac{I_t - \delta K_{t-1}}{K_{t-1}} \mid \psi_t \right) &= \text{Probability}(\varepsilon_t > -\gamma Z_{t-1}) \cdot \gamma Z_{t-1} \\ &+ \text{Probability}(\varepsilon_t > -\gamma Z_{t-1}) \cdot E(\varepsilon_t \mid \varepsilon_t > -\gamma Z_{t-1}) \\ &= \Phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right] \cdot \gamma Z_{t-1} + \sigma_1 \phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right], \end{aligned} \tag{18}$$

where Φ and ϕ are a cumulative distribution function and density function for a standard normal variable respectively.[13] From (18), we can derive the reduced form to be estimated as

$$\frac{I_t - \delta K_{t-1}}{K_{t-1}} = \Phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right] \cdot \gamma Z_{t-1} + \sigma_1 \phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right] + V_t, \tag{19}$$

where

$$V_t = 1[\varepsilon_t > \gamma Z_{t-1}] \cdot (\gamma Z_{t-1} + \varepsilon_t) - \Phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right] \cdot \gamma Z_{t-1} - \sigma_1 \phi\left[\frac{\gamma Z_{t-1}}{\sigma_1}\right] + \eta_t.$$

Note that $E(V_t \mid \psi_t) = 0$ but the disturbance V_t is heteroskedastic. In our empirical work, we use Nonlinear Least Squares (NLS) estimators of γ and σ_1. We also derive a consistent variance-covariance matrix following White's (1980) correction for NLS estimators in the presence of heteroskedasticity.

A few remarks on our estimation strategy are in order. First, one can easily see that our model is basically a Tobit model with measurement errors on the dependent variable. Therefore, alternative way of estimating (19) is by maximum likelihood. However, as Stapleton and Young (1984) pointed out, the conventional maxi-

[13] For a derivation of the conditional expectation of a truncated random variable, see Greene (1990), Chapter 21.

mum likelihood estimator (Tobit) is inconsistent in the presence of measurement errors. Correct maximum likelihood estimation requires specification of the joint distribution of the structural disturbance ε_t and the measurement error η_t. Instead, our approach is to get estimators based on the expectation function of the dependent variable as in Stapleton and Young (1984). These estimators are consistent whether or not measurement errors are present. Of course, the disadvantage is that they are asymptotically less efficient than a correctly specified Tobit procedure.

Second, note that we are estimating the mongrel parameters γ instead of estimating the structural parameters α and β separately. One can consider two approaches to estimating α and β separately. One approach is to use a generated regressor: Estimate β from (15) and use the fitted value in (14). The other is an instrumental variable approach using lagged Z_t's as instruments. Under both approaches, our model becomes an example of an errors-in-variables problem in a non-linear regression model. Y. Amemiya (1985) and Hsiao (1989) explain why the two approaches mentioned above cannot yield consistent estimators in our non-linear setting in contrast to the case when the model is linear. Since our main objective is to compare the goodness of fit among the various investment equations, we decided not to estimate α and β separately through FIML or the method suggested by Hsiao (1989).

In addition to the irreversible investment model described above, we estimate the following two models based on convex adjustment costs.

$$\frac{I_t - \delta K_{t-1}}{K_{t-1}} = d_0 + d_1 Z_{t-1} + \eta_t, \tag{20}$$

$$\frac{I_t - \delta K_{t-1}}{K_{t-1}} = k_0 + k_1 q_{t-1} + k_2 q_{t-2} + \eta_t. \tag{21}$$

In equation (20), the variables in Z capture the gap between desired capital and current capital. Partial adjustment speed is a part of the mongrel coefficient d. Depending on what variables constitute Z, we can interpret (20) as the well known "flexible accelerator model" or the "Jorgensonian neoclassical investment equation".[14] We restrict Z to be the same set of variables used in estimating the desired capital stock in the irreversible investment model in Section

[14]For a detailed description of these models, see Clark (1979).

II. Equation (21) is a typical reduced form in q theory (Hayashi 1982; Blanchard *et al.* 1990). The three models mentioned above are formally tested against each other using the *J* test procedures proposed by Davidson and MacKinnon (1981) for non-nested hypotheses.

IV. Empirical Result

Our sample consists of 56 companies selected from the data constructed by Rhee and Rhee (1991). The source of the data is an expanded version of COMPUSTAT tapes which spans 1963 through 1988. Sample exclusion criteria, the method of evaluating assets and liabilities of the firm's balance sheet at market prices, and the construction of Tobin's q are described in detail in the appendix to Rhee and Rhee (1991), which is available by request. Briefly, (1) the companies which are in agriculture, mining, construction, and public administration industries, whose key variables are missing, or which experienced a major merger with companies of similar size are excluded.[15] (2) the replacement cost of equipment and structures are constructed separately by the perpetual inventory method, (3) the replacement cost of inventories is constructed depending on the accounting methods each firm adopts, and (4) the market values of long term debts are constructed by assuming 20 year maturity and BAA coupon rates.

Among 319 available firms, we chose the following 56 firms: 15 Dow Jones companies to represent large firms. 18 companies are randomly selected from firms whose average market value of capital belongs in the bottom 20 percent of the sample to represent small companies. 14 firms are randomly selected from primary metal, fabricated metal, and transportation equipment industries to represent heavy industries. 9 firms in retail and finance industries are selected to represent "light" industries. The names of all companies together with their identification numbers (CNUM) in COMPUSTAT are listed in Appendix.

[15]In COMPUSTAT data, (stock) price data (annual data item #22-24) are reported as Not Available for those periods in which a major merger of companies of similar size occurs. By excluding companies which have a missing observation in price data, these companies are excluded.

A. Net Investment Specification

Our dependent variable is net investment over (one year lagged) capital. Logarithms of sales (one and two year lagged) over capital (one year lagged), and real interest rates are used as independent variables. In general, using net cash flows instead of sales and introducing real wage rates as an additional independent variable did not change our results. Interest rates are measured by BAA corporate bond yields, and wage rates by an industry specific average hourly earnings index.[16] Real values are calculated from industry specific producer price indices. The results from the estimation of the irreversible investment model revealed that our samples can be classified into three different categories. Below we present the detailed results for the three firms, Rymer Co., Coca-Cola Co., and Harsco Co., which are typical examples from each category.

Table 1 presents the regression results for Rymer Co. Considering the limited number of observations and explanatory variables, the flexible accelerator model performs reasonably well. *R*-squared is quite high (63%) and the Durbin-Watson statistic is close to two. As many previous studies have found, the performance of the q model shows that q is at best one of several significant explanatory variables for investment. In terms of explanatory power, other variables such as sales and cash flows dominate q.[17] In contrast, note the remarkably high *R*-squared (94%) of the irreversible investment model.[18] This increase is easily explained by Figure 1 which contains plots of the fitted values of net investment from each

[16]Judging from the fact that most investment is financed by retained earnings, dividend yields rate might be preferable to real BAA yields rates. The robustness will be checked.

[17]However, as argued in Blundell *et al.* (1987) and Hayashi and Inoue (1991), one should expect that these variables are significant in OLS regressions if the error term in the q equation includes a technology shock to the adjustment cost function. Blanchard *et al.* (1990) consider bubbles in stock prices as a potential reason for the poor performance of q models.

[18]Note that the standard error of γ is extremely small. This results from the fact that we are virtually estimating the three coefficients in γ from three spikes in net investment. This suggests that an ideal example of the irreversibility specification needs many spikes as well as many zeros to be able to estimate γ correctly. In future work, we will use panel regressions to overcome this problem.

TABLE 1
TYPE I (RYMER CO.)
Sample Period: 1965-1988
Dependent Variable: I_t/K_{t-1}(Net Investment(t)/Capital($t-1$))

Flexible Accelerator Model (OLS)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	0.095	0.077
log(sales/capital($t-2$)	0.308	0.075
real interest rate($t-1$)	0.0022	0.005
R-squared	0.63	
D.W.	1.84	

Q Model (OLS)

Independent Variables	Coefficient	Standard Error
Q($t-1$)	0.090	0.05
Q($t-2$)	0.008	0.05
R-squared	0.28	
D.W.	2.35	

Irreversible Investment Model (NLLS with White Correction)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	-0.130	6.9E-07
log(sales/capital($t-2$)	1.113	9.4E-07
σ_1	0.001(fixed)	
R-squared	0.94	

J Tests

Null	Alternative	Test Results
Irreversibility	Flex. Accelerator	0.55/Do Not Reject Null
Flex. Accelerator	Irreversibility	14.3/Reject Null
Irreversibility	Q	0.9/Do Not Reject Null
Q	Irreversibility	17.6/Reject Null
Flex. Accelerator	Q	-0.2/Do Not Reject Null
Q	Flex. Accelerator	4.3/Reject Null

Note: The numbers in the last column are t-statistics of the coefficient of the fitted values of independent variable under the alternative hypothesis.

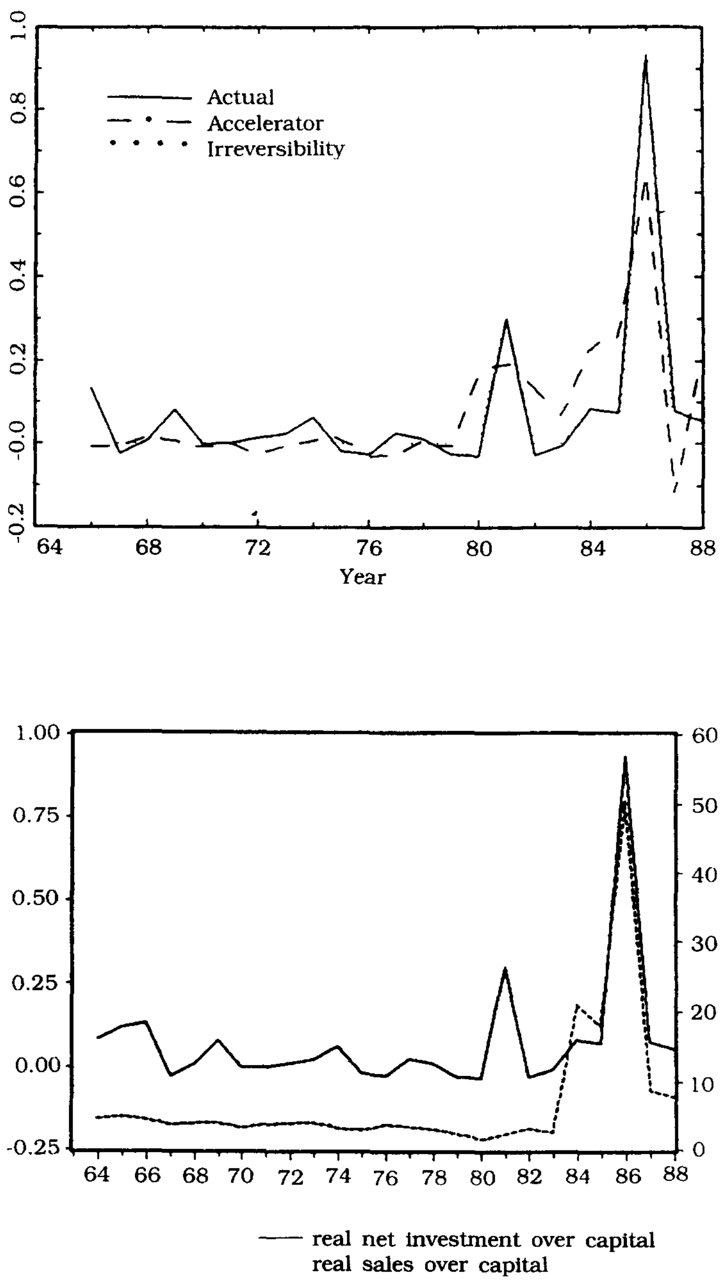

FIGURE 1

RYMER CO.

model, actual net investment, and sales. Net investment for this company is close to zero most of the time except for the big spikes in 1981 and 1986. Technically speaking, by treating small fluctuations around zero as measurement errors and matching the big spikes closely, the irreversible investment model dominates the flexible accelerator. If there is evidence for lumpy adjustment, this picture seems to be an ideal one. The relative performance of these non-nested models are formally compared by J tests in the last panel. As expected, the J tests show that the irreversible investment model cannot be rejected by the others at the 95% significance level, whether it is null or alternative. Henceforth, we will classify companies as Type I if their irreversible investment specification shows significant improvement in R-squared over the flexible accelerator model. Note that this does necessarily imply that the J tests strictly prefer the irreversible investment model for every Type I firm.

Table 2 presents the regression results for Coca-Cola Co., a typical example of what we will call a Type II company. Plots of investment, sales, and fitted values are in Figure 2. The plots indicate that net investment is significantly positive most of the time. The performance of the irreversible investment model can be easily predicted by considering an analogy: If there aren't many zeros in the data, a censored regression model such as Tobit would give very close estimates to OLS. Regression results in Table 2 confirm this. The estimates of the irreversible investment model are identical to the OLS estimates of the flexible accelerator model. Note that we set σ_1 equal to 0.001 in the reported table. Without restriction, we found that σ_1 approaches zero for this firm.[19] However, a grid search showed that the value 0.01 is small enough for σ_1 to make the estimated values of the cumulative distribution function, $\Phi(\gamma Z_{t-1}/\sigma_1)$, very close to one, and that the improvement in performance from reducing σ_1 further is negligible. Since the fitted values are the same, J testing would be useless due to multicollinearity. In terms of matching OLS results, Coca-Cola Co. is an extreme example. Firms whose estimates for the irreversible model are not exactly the same as, but close to, those for the flexible accelerator model are also classified as Type II. We consider that

[19]This pattern is not the same across all Type II firms. There are many firms for which σ_1 converges to a small number.

TABLE 2
TYPE II (COCA-COLA CO.)
Sample Period: 1965-1988
Dependent Variable: I_t/K_{t-1}(Net Investment(t)/Capital($t-1$))

Flexible Accelerator Model (OLS)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	0.556	0.127
log(sales/capital($t-2$)	-0.104	0.120
real interest rate($t-1$)	0.0023	0.0012
R-squared	0.73	
D.W.	1.42	

Q Model (OLS)

Independent Variables	Coefficient	Standard Error
Q($t-1$)	0.014	0.008
Q($t-2$)	-0.006	0.008
R-squared	0.22	
D.W.	0.47	

Irreversible Investment Model (NLLS with White Correction)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	0.556	
log(sales/capital($t-2$)	-0.104	
real interest rate($t-1$)	0.0023	
σ_1	0.001(fixed)	
R-squared	0.73	

firms which belong to this type show no evidence for the irreversible investment model.[20]

Harsco Co. illustrates the usual results for companies of Type III.

[20]Technically speaking, we cannot distinguish the irreversible investment model from the accelerator model in this case. One possible interpretation is that the irreversible investment model is correct but the constraints are not binding. However, there would be little chance for this to happen in sufficiently large samples.

As shown in Figure 3, average net investment of this company is small and its fluctuation lies within a smaller band relative to the other types. Interestingly, the huge estimates of σ_1 and the coefficients of the irreversible investment model (Table 3) show the mechanical way by which our NLLS estimator captures these small deviations from zero. By assigning a large σ_1 and an extremely large control barrier (large estimates of γ), the model minimizes the sum of squared residuals by treating all investment fluctuation as resulting from either measurement errors or information errors. To avoid this mechanical solution, we estimate the irreversible investment model by restricting σ_1 to be a small number, usually 0.1, 0.01, and 0.001.[21] The resulting estimates are usually very close to those in the flexible accelerator model. We found that this pattern, moving from type III to type II when σ_1 is fixed to be small, is quite robust: Type III is essentially a variant of type II.

So far we have introduced three different types of firms in our sample. Table 4 summarizes the number of firms in each type.[22] Most of our sample (46 out of 56) belongs to either Type II or III. But the pattern is quite different across groups. Among small firms, 7 out of 18 companies belong to Type I, and 5 of them strictly prefer the irreversible investment model. But none of the 15 Dow Jones companies support the irreversible investment model. The finding, if confirmed, that the irreversible investment model fits better for small firms is quite suggestive. Large and mature companies may have more stable and predictable business conditions so that the potential overcapacity due to irreversibility is not a serious problem. Also, through more diversified projects or multiplant operation, large firms may have better margins for adjusting to the overcapacity problem internally.

Another factor which we though could affect the relevance of irreversibility is the degree of specificity of the capital stock. As capital becomes more industry specific, the used-capital market would get

[21]Implicitly we are assuming that the information gap is small. Alternatively, we are approximating an index function in the manager's problem (equation (14)) using a cumulative normal distribution. As σ_1 approaches zero, Φ function approaches the index function. this approximation has been frequently used in switching regression models. See Goldfeld and Quandt (1972).

[22]A "(*)" after the company number indicates that the irreversible investment model strictly dominates the others in J tests.

TABLE 3
TYPE III (HARSCO CO.)
Sample Period: 1965-1988
Dependent Variable: I_t/K_{t-1}(Net Investment(t)/Capital($t-1$))

Flexible Accelerator Model (OLS)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	0.136	0.066
log(sales/capital($t-2$)	-0.132	0.056
real interest rate($t-1$)	-0.0017	0.0009
R-squared	0.41	
D.W.	2.23	

Q Model (OLS)

Independent Variables	Coefficient	Standard Error
Q($t-1$)	-0.064	0.052
Q($t-2$)	0.079	0.052
R-squared	0.11	
D.W.	1.59	

Irreversible Investment Model (NLLS with White Correction)

Independent Variables	Coefficient	Standard Error
log(sales/capital($t-1$)	8120	
log(sales/capital($t-2$)	-5720	
real interest rate($t-1$)	-55	
σ_1	9079	
R-squared	0.45	
With σ_1 fixed at 0.01		
log(sales/capital($t-1$)	0.137	0.0172
log(sales/capital($t-2$)	-0.131	0.0378
real interest rate($t-1$)	-0.0017	0.0199
R-squared	0.41	

J Tests

Null	Alternative	Test Results
Irreversibility	Flex. Accelerator	Multicollinearity
Flex. Accelerator	Irreversibility	Multicollinearity
Irreversibility	Q	3.6/Reject Null
Q	Irreversibility	3.4/Reject Null
Flex. Accelerator	Q	1.4/Do Not Reject Null
Q	Flex. Accelerator	3.4/Reject Null

Note: The numbers in the last column are t-statistics of the coefficient of the fitted values of independent variable under the alternative hypothesis.

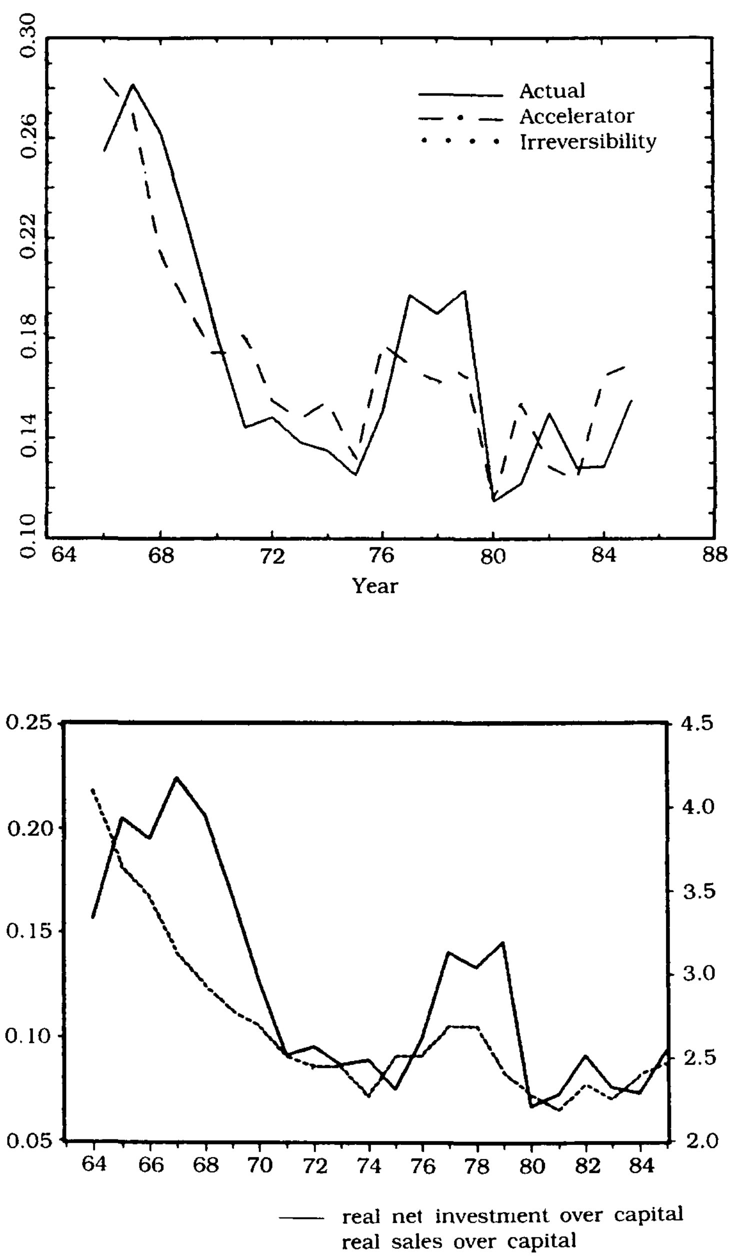

FIGURE 2

COCA-COLA CO.

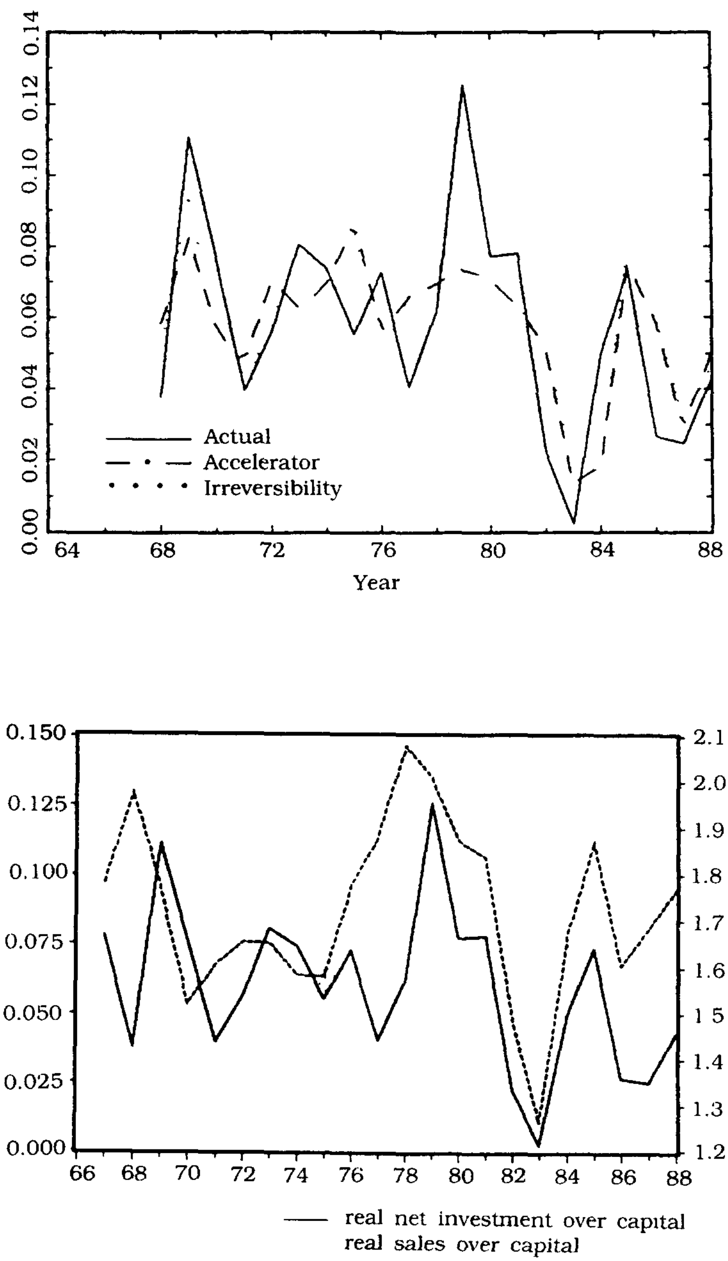

Figure 3
Harsco Co. (Estimated sig_e)

thinner. Although there is no obvious measure of specificity, the measured longevity of capital stocks may be a good proxy as argued by Bizer and Sichel (1991). In addition to the conjecture that longer-lived capital tends to be more industry specific, there is good reason to believe that short-lived capital makes the irreversibility constraints less likely to bind: It depreciates quickly. To test the validity of this prediction, we examined the results from our sample of 14 heavy industry companies which, Bizer and Sichel (1991) found, have longer average capital longevity. These are compared with the 9 companies from the "light" industries. Preliminary results in Table 4 show no evidence for the conjecture. Even though 2 firms in the heavy industries belong to type I, none of them strictly prefer the irreversible investment model.

In summary, only 5 firms out of the sample of 56 companies show favorable evidence for the irreversible investment model. Whether this proportion is significant evidence in favor of non-convex adjustment costs depends on one's prior, but we regard this evidence as too weak for favoring irreversibility. However, it may be premature to discredit the irreversible investment model at this stage. First, our data is annual. The concept of irreversibility is naturally dependent on the length of the unit period chosen. At daily frequency, investment must be trivially irreversible. We therefore believe that the irreversible investment model would have a better chance with quarterly dta. Also, the larger number of observations in quarterly data will allow richer parameterizations of the model. Second, inter-industry comparisons should be extended to a larger number of firms and industries. The re-classification of firms by both size and industry is clearly called for in future work. Until further evidence from the future work mentioned is available, we would like to postpone the final verdict on non-convex adjustment costs.

B. Gross Investment Specification

From the evidence presented in Table 4, one can easily guess what the results were when gross investment was the dependent variable. Since gross investment is positive most of the time, the irreversible investment model yields similar estimates to the flexible accelerator model. Almost all companies belong to Type II. We found only one firm favoring the irreversible investment model out of the

TABLE 4

CLASSIFICATION OF SAMPLE INTO FIRM TYPES

	Type I	Type II	Type III
Small Firms	18(*), 44(*) 8(*), 53(*) 47(*), 1 29	49, 7 30, 54 48, 42 38, 14	20, 39 37
Large Firms (Dow Jones Companies)	9	12, 26 36, 55 11, 16 4, 10 25, 19 57, 3 51	35
Heavy Industries (Primary Metal, Fab. Metal, Trans. Equip.)	52, 43	5, 41 40, 21 13, 23 28, 46	33, 22 6, 50
Light Industries (Retails and Finance)		17, 2 15, 32 34, 27 24, 56	31

Note: 1. Numbers in the table are the company numbers listed in Appendix.
2. (*) indicates that *J* tests strictly prefer the irreversibility specification.

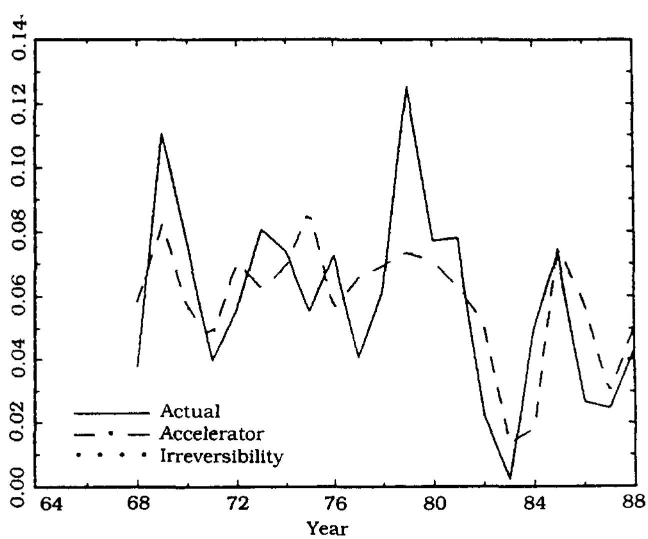

FIGURE 4

HARSCO CO.(SIG_E=0.01)

18 small firms. There is some truth in saying that one need not test non-convex adjustment cost models for gross investment under the assumption that capital is homogeneous; We simply do not observe enough zeros in gross investment series.

V. Summary

This paper empirically tests an irreversible investment model against two models of convex adjustment costs using COMPUSTAT panel data. Under the assumption that capital is homogeneous and irreversible, the derived reduced form of the irreversible investment model turns out to be a Tobit model with measurement errors in the dependent variable. Our empirical results indicate that the evidence for the irreversible investment model is weak: Only 5 firms among our total sample of 56 firms strictly prefer the irreversibility specification.

However, our test might be biased since the assumption of homogeneity of capital is too restrictive against the irreversible investment specification: If capital is heterogeneous and irreversible, we would expect to observe spikes in investment from positive levels not from zero unlike our Tobit specification. To test a formal model with heterogeneous capital, we need to explicitly aggregate different types of investment within each firm. This is conceptually different from the type of aggregation exercises conducted in Bertola and Caballero (1990) and Caballero and Engel (1991), where aggregation is across firms rather than within firms. Carrying out the aggregation and deriving a new reduced form for estimation would be an important topic in future research.

Appendix: List of Companies

Num.	Cnum	Company Name	SIC
1.	01204110	Alba-Waldensian Inc.	2250
2.	01447610	Alexander & Alexander	6411
3.	01951210	Allied Signal Inc.	3724
4.	02224910	Aluminum co of America	3334
5.	02312710	Amax Inc.	3334
6.	04341310	Asarco Inc.	3330

Num.	Cnum	Company Name	SIC	
7.	06879810	Barry (R.G.)	3140	
8.	08725710	Bethlehem Corp.	3443	
9.	08750910	Bethlehem Steel Corp.	3312	
10.	14912310	Caterpillar Inc.	3531	
11.	16675110	Chevron Corp.	2911	
12.	19121610	Coca-Cola Co.	2080	
13.	23456910	Dollas Corp.	3442	Over-the-Counter
14.	25666910	Dollar General	5331	
15.	29442910	Equifax INc.	6411	
16.	30229010	Exxon Corp.	2911	
17.	34555010	Forest City Entrprs.	5031	
18.	36236010	GTI Corp.	3679	
19.	36960410	General Electric Co.	3600	
20.	40918910	Hampton Industries	2320	
21.	41030610	Handy & Harman	3350	
22.	41586410	Harsco Co.	3440	
23.	42829010	Hexcel Corp.	3460	
24.	44175810	House of Fabrics Inc.	5940	
25.	45920010	IBM	3570	
26.	46014610	Intl Paper Co.	2631	
27.	48258410	K Mart Corp.	5331	
28.	48354810	Kaman Corp.	3728	Over-the-Counter
29.	49262010	Ketchum & Co.	5122	
30.	52078610	Lawter International Inc.	2890	
31.	53625710	Lionel Corp.	5945	
32.	57174810	Marsh & Mclennan Cos.	6411	
33.	57459910	Masco Corp.	3430	
34.	58574510	Melville Corp.	5600	
35.	58933110	Merck & Co.	2834	
36.	60405910	Minnesota Mining & MFG	2670	
37.	61583610	Moore Products Co.	3823	Over-the-Counter
38.	62475210	Mueller Co.	3443	Over-the-Counter
39.	62632010	Munsingwear Inc.	2340	
40.	65655910	Nortek Inc.	3444	
41.	70554010	Peerless Tube Co.	3411	
42.	70738910	Penn Engineering & MFG	3452	
43.	71726510	Phelps Dodge Corp.	3330	
44.	78377110	Rymer Co.	2013	
45.	81611910	Selas Corp of America	3567	

Num.	Cnum	Company Name	SIC	
46.	81732010	Sequa Corp.	3490	
47.	82661910	Signal Apparel Co.	2250	
48.	86835810	Superior Surgical MFG	2300	
49.	87156510	Synalloy Corp.	3490	
50.	87264910	TRW Inc.	3760	
51.	88169410	Texaco Inc.	3760	
52.	88320310	Textron Inc.	3720	
53.	89051610	Tootsie Roll Inds	2060	
54.	89585320	Triangle Corp.	3420	
55.	90558110	Union Carbide Corp.	2821	
56.	94901710	Weisfields Inc.	5944	Over-the-Counter*
57.	96040210	Westinghouse Electric	3812	

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