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THE RELATIONSHIP OF FIRM GROWTH AND Q WITH MULTIPLE CAPITAL GOODS: THEORY AND EVIDENCE FROM PANEL DATA ON JAPANESE FIRMS

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ABSTRACT

We develop a Q model of investment with multiple capital goods that delivers a one-to-one relation between the growth rate of the capital aggregate and the stock market-based Q. We estimate the growth-Q relation using a panel of over six hundred Japanese manufacturing firms taking into account the endogeneity of Q. Identification is achieved by combining the theoretical structure of the Q model and an assumed serial correlation structure of the technology shock that comprises the error term in the growth-Q relation. The Q variable is significantly related to firm growth. Much, but not all, of the apparent explanatory power of cash flow disappears if its endogeneity is corrected for. The estimated Q coefficient is not implausibly small if the growth rate of the capital aggregate contains measurement error.

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1. INTRODUCTION AND SUMMARY

This paper uses a panel of several hundred Japanese manufacturing firms to estimate the investment-Q relation. The investment-Q relation is a first-order condition for the firm's dynamic optimization with adjustment costs and states that the marginal adjustment cost of investment be equal to the shadow price of capital. For competitive firms under constant returns to scale, this relation is operational because the unobservable shadow price is directly linked to the stock market valuation of existing capital (Lucas and Prescott (1971) and Hayashi (1982)), which allows one to estimate the parameters that characterize the adjustment cost function. The estimated parameters are structural in Lucas's sense: they are invariant to the structure of the environment faced by the firm because it is fully captured by the shadow price.

Despite its considerable theoretical appeal, empirical performance of the investment-Q relation has been disappointing. Studies based on aggregate time-series data include von Furstenberg (1977) and Summers (1981) for the US, Poterba and Summers (1983) for the UK and Hayashi (1985) for Japan. Studies using micro data are relatively few, probably because of the non-trivial nature of tax adjustments to be applied to each individual firm. Most recent micro studies (which are predated by the first draft of the paper) include Blundell, Bond, Devereux and Schiantarelli (1987) for the UK and Fazzari, Hubbard and Petersen (1988) for small US firms and Hoshi and Kashyap (1987) for Japan. A consensus result that emerges from the existing empirical studies is that Q is at best one of the few significant explanatory variables for investment. The Q coefficient is implausibly small, while other variables like output, profits or cash flow often proves to be more strongly associated with investment. We think that it is yet too early to discredit the model of dynamic optimization with adjustment costs under perfect competition -- upon which the investment-Q relation is based -- for a couple of reasons. First, with a possible exception of Blundell et. al. (1987), the existing studies do not seem to have carefully examined possible biases due to the fact that Q is endogenous. As we will argue in section 4 and is summarized below, the Q model predicts that ordinary least squares should find variables like cash flow and output to be significant if added to the investment equation along with Q. Second, the Q model that has been estimated does not explicitly incorporate multiple capital goods. There are as many shadow prices as there are capital goods. The stock market valuation of the firm is an average of those shadow prices. Only under a set of very stringent assumption there exists a relationship between the sum of nominal investments and the stock market-based Q which is independent of the composition of investments.[1]

These two issues are fully addressed in the paper. Instead of associating the sum of investments to Q, we construct a Q model with multiple capital goods in which adjustment costs are related not to individual investments but to the growth rate of a scalar aggregate of multiple capital goods. This delivers a one-to-one relation between the growth rate of the capital aggregate and the stock market-based Q. Furthermore, since no adjustment costs are incurred in re-shuffling the composition of capital stocks holding constant the growth rate of the capital aggregate, our Q model inherits a basic implication of the Jorgensonian neoclassical investment theory without adjustment costs that the marginal rate of substitution between different capital goods is the ratio of their user

[1] The conditions derived by Wildasin (1984) include fixed prices of capital goods over time and separable but identical adjustment cost functions across capital goods.

costs of capital, which implies that the capital aggregate in our Q model is precisely the quantity index of capital inputs routinely calculated in the literature on productivity growth (see Jorgenson (1986) for a review) using the user costs of capital as weights.[2]

Our Q model with multiple capital goods is confronted by micro data on several hundred Japanese manufacturing firms listed on the Tokyo Stock Exchange over a ten year period from 1977 to 1986. Our data set has a few distinctive advantages. There is a breakdown of investment expenditure between several asset types, which makes it possible for us to carry out an explicit index number construction. Unlike most western countries, mergers and acquisitions are quite few in Japan. In 1977 there were 942 manufacturing firms listed on the Tokyo Stock Exchange. Only 62 of them failed to be listed throughout the period due to mergers and bankruptcies. Thus there is very little attrition bias. The virtual lack of mergers and acquisitions also means that almost all the firms in the sample grew at the same margin -- through internal expansion, not through acquisitions. Furthermore, the unit of observation is a listed firm defined by unconsolidated accounts.[3] The Q model is arguably better suited to this smaller unit than to a whole of a collection of companies headed by a parent company.

The issue of endogeneity of Q is taken seriously in our estimation of the firm growth-Q relation. The error term in the growth-Q relation is a shock to the profit function, and this shock, besides its direct impact on output and cash

[2] In the productivity literature the equality of the marginal productivity of capital and the user cost of capital is used for the index number construction. To justify the index number, all that is necessary is that the marginal productivity be proportional to the user cost of capital across capital goods, the condition satisfied in our Q model.

[3] For example, our sample includes Toshiba, Toshiba Machine, and Toshiba Kokan. There are eight Hitachi's and thirteen Mitsubishi's in the sample.

flow, would affect a wide range of variables pertaining to the firm including Q. This consideration rules out the use of "extraneous" instruments. We achieve identification by combining the structure of the Q model and an assumed serial correlation structure of the error term. We eliminate the permanent component of the error term by taking first differences of the growth-Q relation, while correlation of the temporary component with Q is circumvented by the use of lagged (and for some cases future) endogenous variables as instruments.

Our empirical results are on the whole favorable to the Q model. The Q variable is significant in the estimated growth-on-Q equation that passes our diagnostic checking. If cash flow is included in the equation, it is significant but less so than the Q coefficient and accounts for a much smaller fraction of the cross section variation of the firm growth than Q does. The only puzzling feature of our estimated Q model is that the estimated Q coefficient is so small that the firm growth generates a large variation in the level of adjustment costs which on average is far higher than the size of cash flow. However, much of the variation can be due to measurement error in the growth rate of the capital aggregate. Indeed, if we attribute all the temporary component of the disturbance to the growth-Q relation to measurement error in the growth rate, about two-thirds of the cross section variance of the growth rate is due to measurement error. But it still is the case that the Q coefficient is too small because the level of adjustment costs attributable to the true value of the firm growth rate is on average slightly higher than cash flow.

The organization of the paper is as follows. Section 2 is a theoretical section where our Q model with multiple capital goods is presented. Measurement and econometric issues are discussed in sections 3 and 4, respectively. Section 5 reports our empirical results.

2. A Q MODEL WITH MULTIPLE CAPITAL GOODS

We consider a standard discrete-time, stochastic model of the firm's value maximization with adjustment costs. It is well known that for the case of single capital good there is a one-to-one relation between investment and "average Q" (Hayashi (1982)). Here we generalize it to the case of n capital goods. The firm is assumed to maximize its value V_t:

$$(2.1) \quad V_t = E_t \left\{ \sum_{j=0}^{\infty} \beta_{t,j} * \{ (1-\tau_{t+j}) [OP_{t+j} * F(K_{t+j}+N_{t+j}, N_{t+j}, p_{t+j}, u_{t+j}) - DEP_{t+j}] - \sum_{i=1}^{n} PK_{i,t+j} * I_{i,t+j} \} \right\}$$

$$\text{subject to} \quad K_{i,t+j+1} = (1-\delta_i)*(K_{i,t+j} + I_{i,t+j}) \qquad (i=1,..,n),$$

where $K_t = (K_{1t},..,K_{nt})$ is an n-vector of capital stocks, N_t is an n-vector of net investments, OP_t is the price of the firm's output, PK_{it} is the price of the i-th capital good, p_t is a vector of real factor prices, I_{it} is gross investment in the i-th capital good, δ_i is the physical depreciation rate for capital good i, τ is the corporate tax rate, DEP is depreciation write-offs for tax purposes on past investments, E_t is the expectations operator conditional on the time t information set, and $\beta_{t,j}$ is the (possibly stochastic and time-varying) discount factor applicable in period t to j-period-ahead payoffs with $\beta_{t,0} = 1$ and $\beta_{t,j} = \beta_{t,1}*...*\beta_{t+j-1,1}$. The profit function F does not explicitly involve variable inputs (energy, labor, material inputs) because they are already maximized out.[4] The

[4] Let L be the vector of variable factor inputs and G(K+N,L,N) be the production function defined over the capital stock, variable factor inputs, and net investment. Then nominal profits equal $(1-\tau)*OP*[G(K+N,L,N)-pL]$. The profit function F is the maximized value of the expression in brackets over choices of L. The maximized value F depends on real factor prices which is given to the firm.

vector of net investments N_t enters F with negative partial derivatives to represent adjustment cost in changing the capital stocks. The term u represents a technology shock to the profit function. Note the timing convention adopted here. Current investment without any lags starts contributing to current production (which is indicated by the fact that production in period t depends on $K_{t+1} = K_t + N_t$), albeit with adjustment costs.[5] Current investment also starts depreciating immediately as they are employed in production, so that the relationship between net investment N_t and gross investment I_t is:

$$(2.2) \qquad N_{it} = I_{it} - \delta_i*(I_{it} + K_{it}) \quad \text{or} \quad I_{it} = (N_{it} + \delta_i K_{it})/(1-\delta_i).$$

As noted in Hayashi (1982) the expression for the value of the firm can be broken down to two parts:

$$(2.3) \qquad V_t = W_t + A_t,$$

where A_t is the expected present value of tax savings due to depreciation allowance yet to be claimed on past investments, and W_t is the value of the firm evaluated at tax-adjusted capital goods prices:

$$(2.4) \qquad W_t = E_t \{ \sum_{j=0}^{\infty} \beta_{t,j}*[(1-\tau_{t+j})*OP_{t+j}*F(K_{t+j}+N_{t+j}, N_{t+j}, p_{t+j}, u_{t+j}) - \sum_{i=1}^{n} (1-z_{i,t+j})*PK_{i,t+j}*I_{i,t+j}] \},$$

[5] As shown below, this timing specification implies that current investment is related to the beginning of the period Q. On the other hand if there is a one-period lag between investment and production, current investment is related to the end of the period Q. In our data current investment is much more strongly correlated with the beginning of the period Q than to the end of the period Q.

where z_{it} is the expected present value of tax savings due to depreciation allowances on one dollar of investment in the i-th capital good in period t. Since A_t is given to the firm in period t, the value maximization amounts to maximizing W_t subject to the capital accumulation constraint $K_{t+1} = K_t + N_t$. The current state consists of the vector of initial capital stocks K_t and a first-order Markov process $\{s_t\}$ such that all prices and shocks (OP_t, PK_t, p_t, $\beta_{t-1,1}$, τ_t, z_t, u_t) are functions of s_t. This vector s_t is exogenous in that the firm, being competitive, has no control over it. The current decision is the n-vector N_t. The maximized value of W_t is a function of the state (K_t, s_t).

Bellman's equation associated with maximization of W_t is:

$$(2.5) \qquad W(K_t,s_t) = \max_{N_t} \{(1-\tau_t)*OP_t*F(K_t+N_t,N_t,p_t,u_t) - \sum_{i=1}^{n} (1-z_{it})*PK_{it}*I_{it} + E[\beta_{t,1}W_{t+1}(K_t+N_t) \mid s_t]\}.$$

Two sets of the first-order conditions can be derived. The first set is the first-order conditions for maximization of the term in braces in (2.5) with respect to N_t. The second set can be obtained from differentiating both sides of (2.5) with respect to K_t and using the envelope theorem. Let Q_{it} be defined as

$$(2.6) \qquad Q_{it} = \frac{W_{Ki}(K_t,s_t) \;-\; (1-z_{it})*PK_{it}}{(1-\tau_t)*OP_t} \qquad (i=1,..,n),$$

where W_{Ki} is the partial derivative of $W(K,s)$ with respect to K_i. Noting $K_{t+1} = K_t + N_t$, we can write the two sets of first-order conditions as:

$$(2.7) \quad F_{Ki}(K_{t+1},N_t,p_t,u_t) + F_{Ni}(K_{t+1},N_t,p_t,u_t) - J_{it} + E(\beta_{R,t+1}Q_{i,t+1} \mid s_t) = 0 \quad (i=1,..,n),$$

$$(2.8) \quad Q_{it} = F_{Ki}(K_{t+1},N_t,p_t,u_t) - J_{it} + E(\beta_{g,t+1}Q_{i,t+1} \mid s_t) \qquad (i=1,..,n),$$

where F_{Ki} is the partial derivative of $F(K_{t+1},N_t,p_t,u_t)$ with respect to $K_{i,t+1}$ and F_{Ni} is the partial derivative with respect to N_{it} (holding $K_{t+1} = K_t + N_t$ constant), and J_{it} is the Jorgensonian user cost of capital

$$(2.9) \quad J_{it} = \frac{(1-z_{it})*PK_{it}/(1-\delta_i) - E[\beta_{t,1}*(1-z_{i,t+1})*PK_{i,t+1} \mid s_t]}{(1-\tau_t)*OP_t} \qquad (i=1,..,n),$$

and $\beta_{g,t+1}$ is the one-period real discount factor:

$$(2.10) \qquad \beta_{g,t+1} = \beta_{t,1}*(1-\tau_{t+1})*OP_{t+1}/[(1-\tau_t)*OP_t].$$

Equation (2.8) says that Q_{it} is the present discounted value of the gap between marginal productivity of capital and the user cost of capital. Subtracting (2.7) from (2.8) we obtain:

$$(2.11) \qquad -F_{Ni}(K_{t+1},N_t,p_t,u_t) = Q_{it} \qquad (i=1,..,n).$$

This is a key equation stating that the marginal adjustment cost be equal the shadow price. Thus conditional on the initial capital stocks K_t, real factor prices p_t, and the technology shock u_t, there is a one-to-one relation between net investments N_t and the shadow prices $(Q_{1t},..,Q_{nt})$. Current investment is related to the beginning-of-the-period shadow prices because current investment is supposed to contribute to current profits which are reflected in the beginning-of-the-period firm value.

If we assume constant returns to scale in production, so that $F(K_t+N_t,N_t,p_t,u_t)$ are linearly homogeneous in (K_t,N_t), then it can be shown that (see Hayashi (1982) for the single good case and Chirinko (1983) and Wildasin

(1984) for the multiple capital goods case):[6]

$$(2.12) \qquad W(K_t,s_t) = \sum_{i=1}^{n} W_{Ki}(K_t,s_t)K_{it} \quad \text{or} \quad \sum_{i=1}^{n} Q_{it}K_{it} = \frac{W_t - \sum_{i=1}^{n}(1-z_{it})*PK_{it}*K_{it}}{(1-\tau_t)*OP_t.}.$$

This says that an aggregate of unobservable individual Q_{it}'s weighted by capital stocks is linked to the financial market valuation W_t of the firm. To make the theory operational, then, we look for a set of restrictions on technology under which there exists a one-to-one relation between this aggregate Q and some index of firm growth. More specifically, assume that there exists a (linear homogeneous) capital aggregator $\Phi(K_{t+1})$ such that

$$(2.13) \qquad F(K_{t+1},N_t,p_t,u_t) = \alpha(y_t,p_t,u_t)*\Phi(K_{t+1}),$$

where

$$(2.14) \qquad y_t = \frac{\Phi(K_{t+1}) - \Phi(K_t)}{\Phi(K_{t+1})} = \frac{\Phi(K_{t+1}) - \Phi(K_{t+1}-N_t)}{\Phi(K_{t+1})}$$

is the growth rate of the capital aggregate.[7] Thus there are no adjustment costs in substituting one capital good for another given the growth of the firm size.

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[6] To prove this, multiply both sides of (2.7) by N_{it} and aggregate over i, and multiply both sides of (2.8) by $K_{i,t+1}$ and aggregate over i. Add them up and use the linear homogeneity of F. Then use the capital accumulation constraint $K_{t+1} = K_t + N_t$ and (2.6), (2.9) and (2.10) to show that the W_t given by (2.12) satisfies Bellman's equation.

[7] Since $K_t = K_{t+1} - N_t$, y_t is a function of K_{t+1} and N_t. Another natural definition of the growth rate is $\log(\Phi(K_{t+1})) - \log(\Phi(K_t))$. Then the growth-Q relation (2.15) below becomes $-\alpha_y(y_t,p_t,u_t)\exp(y_t) = Q_t$. In the empirical part of the paper we will parameterize the left hand side of the growth-Q relation (2.15). Our choice (2.14) for y gives the cleanest expression of the left hand side as a function of y. As long as α is written as a function of $\Phi(K_{t+1})/\Phi(K_t)$, the results below go through.

We are now ready to state our main theoretical results.

PROPOSITION 1: If the firm is competitive and if capital stocks enter the linear homogeneous profit function through a capital aggregator $\Phi(.)$ as indicated in (2.13), then there is a one-to-one relation between the firm growth y_t and a scalar aggregate index Q_t:

$$(2.15) \qquad -\alpha_y(y_t, p_t, u_t) = Q_t,$$

where α_y is the partial derivative of α with respect to y (the negative of the marginal adjustment cost) and

$$(2.16) \qquad Q_t = \frac{\sum_{i=1}^{n} Q_{it}K_{it}}{\Phi(K_t)} = \frac{W_t - \sum_{i=1}^{n} (1-z_{it})*PK_{it}*K_{it}}{(1-\tau_t)*OP_t*\Phi(K_t)}.$$

Furthermore, the marginal rate of substitution in the capital aggregate between any two capital goods equals the ratio of their user costs of capital, which in turn is equal to the ratio of their Q_i's:

$$(2.17) \qquad \frac{\Phi_i(K_t)}{\Phi_{i'}(K_t)} = \frac{J_{i,t-1}}{J_{i',t-1}} = \frac{Q_{it}}{Q_{i't}} \qquad (i,i'=1,..,n),$$

where $\Phi_i(K_t)$ is the partial derivative of $\Phi(K_t)$ with respect to K_{it}.

PROOF: Under the assumed technology (2.13), equation (2.11) becomes

$$(2.11') \qquad -\alpha_y(y_t, u_t)\Phi_i(K_t) = Q_{it} \qquad (i=1,..,n),$$

which, combined with (2.12) and the homogeneity property of the aggregator function $\Phi(.)$, implies (2.15). To show (2.17) we note that (2.7) becomes

$$(2.7') \quad [\alpha(y_t,p_t,u_t) + \alpha_y(y_t,p_t,u_t)(1-y_t)]\Phi_i(K_{t+1}) - J_{it} + E(\beta_{\ell,t+1}Q_{i,t+1}|s_t) = 0$$

$$(i=1,\ldots,n).$$

Shift time forward by one period in (2.11') and substitute it into (2.7') to obtain

$$(2.18) \quad [\alpha(y_t,p_t,u_t) + \alpha_y(y_t,p_t,u_t)(1-y_t)]\Phi_i(K_{t+1})$$
$$- J_{it} - E[\beta_{\ell,t+1}\alpha_y(y_{t+1},p_{t+1},u_{t+1})|s_t]*\Phi_i(K_{t+1}) = 0 \qquad (i=1,..,n),$$

which implies the first equality in (2.17). The second equality is implied by (2.11'). Q.E.D.

REMARK 1: Using (2.3) the scalar index defined in (2.16) is perhaps more conveniently rewritten as

$$(2.19) \qquad Q_t = (q_t - 1)* \frac{P_{\Phi t}}{(1-\tau_t)*OP_t},$$

where q_t is the so-called (tax-adjusted) <u>Tobin's q</u>:

$$(2.20) \qquad q_t = \frac{V_t - A_t}{\sum_{i=1}^{n} (1-z_{it})*PK_{it}*K_{it}},$$

and $P_{\Phi t}$ is the implicit price index for the capital aggregate defined by

$$(2.21) \qquad P_{\Phi t}*\Phi(K_t) = \sum_{i=1}^{n} (1-z_{it})*PK_{it}*K_{it}.$$

We will refer to the asset-aggregated Q defined by (2.16) or (2.19) as the <u>tax-adjusted Q</u>.

REMARK 2: The second part of Proposition 1 is what makes the result operational. Under some standard assumption about the next period's capital good prices, the user cost of capital is observable. Equation (2.17) implies that the marginal productivity of capital is some factor times the user cost of capital and that factor is common to all capital goods. Thus we can employ the standard theory of index numbers to construct using the user costs of capital as weights a discrete time series that closely approximates the capital aggregate $\Phi(K_t)$ without knowing the functional form for the capital aggregator $\Phi(.)$. The series thus constructed is exactly the quantity index of capital inputs which is the main variable in the literature on productivity growth.

The following result about the asset-aggregated Q will be of some relevance in the estimation of the investment-Q relation (2.15).

PROPOSITION 2: The asset-aggregated Q_t is independent of the initial capital stocks: $Q_t = Q(s_t)$, where s_t is the exogenous state of the world.

PROOF: Multiply both sides of (2.7') by $K_{i,t+1}$, aggregate over i, and divide both sides by $\Phi(K_{t+1}) = \Sigma\, \Phi_i(K_{t+1})K_{i,t+1}$, and use (2.16) to obtain

$$(2.22) \qquad [\alpha(y_t,p_t,u_t) + \alpha_y(y_t,p_t,u_t)(1-y_t)] - \frac{\sum_{i=1}^{n} J_{it}K_{i,t+1}}{\Phi(K_{t+1})} + E(\beta_{\ell,t+1}Q_{t+1}|s_t) = 0.$$

Since by (2.15) y_t is a function of Q_t, p_t, and u_t, the expression in brackets in (2.22) is a function of Q_t, p_t, and u_t. Since $\Phi(.)$ is linear homogeneous by definition and since $\Phi_i(K_{t+1})/\Phi_{i'}(K_{t+1}) = J_{it}/J_{i't}$ by (2.17), the ratio term after the bracketed expression is a function of $(J_{1t},..,J_{nt})$ alone. Therefore, equation

(2.22) is a first-order difference equation for Q_t in which the forcing variables are all functions of s_t. Q.E.D.

3. MEASUREMENT

Measurement of the asset-aggregated, tax-adjusted Q as defined by (2.16) requires several steps. First, all financial assets are netted out against liabilities, because the financial market valuation of the equity component of the firm reflects those assets. This requires us to evaluate all the asset and liability items of the firm's balance sheet at market prices. Second, the capital stock K_{it} is constructed for each capital good. Third, tax parameters are incorporated in order to calculate the tax-adjusted prices of capital goods $(1-z_{it})*PK_{it}$ and output $(1-\tau_t)*OP_t$ and the present value of tax saving yet to be claimed on past investments (A_t in (2.3)).[8] Finally, an index of the capital aggregate Φ is constructed.

We carried out these steps for individual Japanese manufacturing firms. A complete documentation of our data set is in the Appendix. Here, we briefly describe its main features.

Capital Stocks Our data on the company financial statements compiled by the Japan Development Bank are detailed enough to provide a breakdown of gross investment between seven capital goods: (1) nonresidential buildings, (2) structures, (3) machinery, (4) transportation equipments, (5) instruments & tools, (6) land, and (7) inventories. Thus we were able to apply different physical

[8] For Japan, the treatment of tax parameters is somewhat complicated because of an implicit interest-free loan granted to corporations through "tax-free reserves" and "special depreciation". See the Appendix for details.

depreciation rates to construct the capital stock by the perpetual inventory method for each capital good. For capital goods (3), (4) and (5), which are internationally tradable, we use Hulten and Wykoff's (1981) physical depreciation rates. For those firms that existed before 1962 their 1962 (end of 1961) book value of capital is used as the benchmark for the perpetual inventory method. For others that were established after 1962, the benchmark is the first year's book value. Gross investment equals the change in the book value of net capital stock plus accounting depreciation. Prior to 1977, accounting depreciation is not available by assets, making it necessary to do some imputations. Afterwards a complete breakdown of gross investment into the seven asset types is available. For this reason we take the sample period for estimation to be 1977-1986. Thus for estimation purposes we will utilize only the recent part of the data construction period (1962-1986). This also serves to minimize the effect of the 1962 benchmark on the calculated capital stock in the estimation period.

<u>The Capital Aggregate</u> To construct the capital aggregate Φ we use the familiar Divisia index:

$$(3.1) \qquad \frac{\Phi(K_{t+1}) - \Phi(K_t)}{\Phi(K_{t+1})} = \sum_{i=1}^{n} \frac{J_{it}*N_{it}}{\sum_{k=1}^{n} J_{kt}*K_{k,t+1}} .$$

Strictly speaking the user cost of capital J_{it} defined by (2.9) is unobservable because it depends on the expectations about the next period's real capital goods prices. The expression (2.9) can be rewritten as

$$(3.2) \qquad J_{it} = \frac{(1-z_{it})*PK_{it}}{(1-\tau_t)*OP_t} \left(\frac{1}{1-\delta_i} - \frac{1}{1+r_{it}}\right) \qquad (i=1,..,n),$$

where

$$(3.3) \qquad 1+r_{it} = \frac{(1-z_{it})*PK_{it}}{(1-z_{i,t+1})*PK_{i,t+1}*\beta_{t,1}} \qquad (i=1,..,n)$$

is the asset i specific real rate of return. Using the gross short term interest rate for $1/\beta_{t,1}$, we calculated for each firm the time mean of the real rate of return for each asset. We used this mean real rate to calculate the user cost of capital.[9] The Divisia index is normalized so that its implicit price index $P_{\phi t}$ (see (2.19)-(2.21)) equals the tax-adjusted output price $(1-\tau_t)*\ OP_t$ in 1980. Thus $Q_t = q_t - 1$ for 1980.

Entity of the "Firm" The firm can grow at several margins: expansion of existing establishments, building new factories, and acquiring other firms. The model of optimal capital accumulation of section 2 is most probably applicable at the establishment level. If so, the entity of the firm in our sample should be close to an establishment, or at least they should grow at the same margin. In this respect our data on Japanese firms are close to being ideal: the stocks listed on the Tokyo Stock Exchange correspond exactly to unconsolidated accounts on which our calculation is based, and only 42 of our sample of 656 firms were an acquirer during the sample period. It might appear that our use of unconsolidated financial statements is unwarranted because the theory may not apply to a (listed) subsidiary whose investment decision is done by the parent company. However, it seems obvious that value maximization for the parent company calls

[9] We also did the index number calculation under perfect foresight about the next period's prices. It however produced a great deal of cross section variation in the growth rate and Q. Results under prefect foresight is mentioned in footnote 18.

for value maximization for its subsidiaries as well. An adjustment cost shock to a subsidiary will be reflected in the value of its shares owned by the parent company, but it is exactly offset by the parent company's share prices, leaving the parent company's Q unaffected by the shock to its subsidiaries. Thus, the theory should apply with equal force to all the firms in the sample (except for the acquirers) provided that, as done in our calculation of Q, stocks of affiliates (subsidiaries and parent companies) held by the firm are valued at market prices.

Sample Selection As explained above, the nature of raw data determined the sample period for estimation to be a ten-year period 1977-86 (or to be more precise, from the fiscal year that ends between April 1977 and March 1978 to the fiscal year that ends between April 1986 and March 1987). Of 942 manufacturing firms listed on the Tokyo Stock Exchange in 1977, 62 firms failed to be listed throughout the sample period (1977-86). We then eliminate 142 firms that changed the fiscal year during the data construction period (1962-86), and 81 firms whose stock prices cannot be found in our stock prices file. This leaves 657 firms. One of them is a very clear outlier in terms of the growth rate of capital due to a massive divestment in 1986. Thus the final sample size is 656.

As a by-product of our calculation of Q, Table I displays our estimate of the market value of balance sheet items which may be of some independent interest. To make the numbers comparable to the parameter estimates to be reported in section 5, we excluded 42 firms who were engaged in mergers and acquisitions. The numbers in the Table are averages -- for the 614 non-acquiring firms whose fiscal year ends between April of the calendar year and March of the next calendar year -- of the individual firm's corresponding entries valued at the beginning of the fiscal year of the firm. The Table indicates that the debt-equity ratio is far lower than commonly thought: the gross debt-equity ratio defined as the ratio of gross debt to equity is less than one for 1986. Another notable feature is the large value of financial assets. This must be largely due to the fact that financial statements are unconsolidated. Since parent companies and/or subsidiaries of manufacturing firms in our sample may not be in manufacturing, we cannot simply net out financial assets and stocks of affiliates against liabilities to arrive at the debt-equity ratio for the Japanese corporate sector as a whole that would have obtained from consolidated balance sheets. But Table I at least suggests that the debt-equity ratio on the consolidated basis could be far less than unity. The last two rows report the tax-adjusted Tobin's q defined in the formula (2.20) calculated in two different ways. The q in the first line is obtained by plugging the averages reported in the Table into the formula. Thus it is the ratio of averages. The second line is the average of q ratios calculated for each individual firm. The two q's differ substantially in levels, although they tend to move together over time.

4. ECONOMETRIC ISSUES

In this section we discuss some econometric issues regarding the estimation of the investment-Q relation in micro data on firms. At this stage we introduce firm subscript "f".

We parameterize the α function in (2.13) as a quadratic function:[10]

$$(4.1) \quad -\alpha(y_{ft},p_{ft},u_{ft}) = a_0(p_{ft},u_{ft}) + [a_1(p_{ft}) + u_{ft}]y_{ft} + (a_2/2)*(y_{ft})^2, \quad a_2 > 0,$$

[10] The intercept term a_0 can depend on technology shocks that are distinct from u_{ft}.

so that the investment-Q relation is written as[11]

$$(4.2) \qquad y_{ft} = -a_1(p_{ft})/a_2 + (1/a_2)*Q_{ft} - u_{ft}/a_2.$$

As is clear from the discussion in section 2, the asset-aggregate Q_{ft} is a (generally nonlinear) function of (among other things) the technology shock u_{ft} that comprises the error term in (4.2). Thus Q_{ft} is in general correlated with the error term in cross section: firms experiencing a technology shock that raises their marginal adjustment cost high relative to other firms would tend to have lower Q. This also means that it would be difficult to find some "external" instruments that have cross-sectional variation and that are uncorrelated with u_{ft}, since any variable connected to production or to adjustment costs are potentially affected by u_{ft}. This point about econometric endogeneity of Q is illustrated by the OLS (ordinary least squares) estimates on the sample pooled across years shown in Table II. There y is regressed on Q and the cash flow rate PAI where PAI is the ratio of the firm's gross after-tax profits (earnings plus accounting depreciation less income tax) to the value of capital aggregate $(1-\tau_{ft})*OP_{ft}*\Phi(K_{f,t+1})$. This PAI is an empirical counterpart of $\alpha(y_{ft},p_{ft},u_{ft})$. The Q variable is significant in the regression of y on Q. But the explanatory power of the regression greatly increases when PAI is added to the regression. This, however, is not inconsistent with the theory because PAI itself is endogenous. Indeed, if the same equation is estimated by OLS in first differences, the strength of PAI is drastically reduced while the estimated Q

[11] The term $a_1(p_{ft})$ in (4.2) differs across firms because real factor prices p_{ft} depend on output price $(1-\tau_t)*OP_{ft}$. However, output price is common to all firms in the same industry. We therefore represent $a_1(p_{ft})$ by industry dummies. See equations (4.3) and (4.4).

coefficient is stable across specifications, suggesting that PAI in the level equation is picking up the firm-specific component of the error term.[12]

Under these circumstances, identification of the parameters can more plausibly be achieved by some a priori restrictions on the serial correlation structure of the error term. We assume that the error term (the technology shock for firm f) at time t can be decomposed into two parts. The first component is a macro shock m_t common to all the firms in the population but can vary over time, while the second component π_{ft} is idiosyncratic to the firm. Now if our sample were a random sample, the idiosyncratic component $\pi_f = (\pi_{f1},\ldots,\pi_{fT})$ (where T is the length of the panel) is a random drawing from a sample path space common to all f. However, unless the process of getting listed on the Tokyo Stock Exchange is random, our sample of about six hundred firms is a universe. Here we follow the usual but often implicit assumption that the correlation between firms in π_f is fully captured by the industry dummies, so that the remaining component (π_{ft} minus industry dummies) can be thought of as a random drawing from a common sample path space. Furthermore, we assume that remaining component can be written as a sum of a permanent component and a temporary component, $v_f + w_{ft}$, where w_{ft} is serially uncorrelated and v_f is independent of $(w_{f1},\ldots,w_{ft})$.[13] Thus, the error term can be written as:

$$(4.3) \qquad -u_{ft}/a_2 = \sum_k b_{kt}{*}IND_{fk} + v_f + w_{ft} \qquad (t=1,\ldots,T),$$

[12] The regressions in the Table do not use industry dummies. Inclusion or exclusion of ten industry dummies made little difference for the level specification and virtually no difference for the first difference specification.

[13] Precisely what we mean by "serially uncorrelated" will be discussed momentarily.

where IND_{fk} is an industry dummy for industry k which takes the value of one if f belongs to industry k.[14] We will use ten industry dummies in the estimation ($k = 1,2,..,10$).[15] As we will see, this standard assumption about the error term will prove to be consistent with the data.

The firm-specific component v_f, being a part of u_{ft}, is correlated with Q_{ft}. We eliminate this by taking first differences of (4.2) to obtain T-1 equations:

$$(4.4) \quad y_{f,t+1} - y_{ft} = \sum_k (b_{k,t+1} - b_{kt})*IND_{fk} + (1/a_2)*(Q_{f,t+1} - Q_{ft}) + (w_{f,t+1} - w_{ft}) \qquad (t=1,\ldots,T-1).$$

Here, we have submerged the $a_1(p_{ft})/a_2$ term in (4.2) with industry dummies because real factor prices p_{ft} is common to all the firms in the same industry. The first difference in Q in equation (4.4) is still endogenous, so we have to find instruments. To this end we strengthen the serial correlation property of w_{ft}. We consider two cases:

(i) $\{w_{ft}\}$ is serially independent.

(ii) $\{w_{ft}\}$ is a martingale difference sequence.

The theory of the firm in section 2 implies that for each f y_{ft}, Q_{ft}, and PAI_{ft} are functions of w_{ft}. Under either (i) or (ii), w_{ft} is uncorrelated with functions of its past values.[16] Thus we can use <u>past</u> values of y, Q and PAI as instru-

[14] Here m_t has been submerged to the industry dummies whose coefficients can be time-dependent.

[15] See the Appendix for definition of the ten industries.

[16] This is not true if $\{w_{ft}\}$ is merely serially uncorrelated. If X is uncorrelated with Y, it does not necessarily mean that X is uncorrelated with a function of Y.

ments. Under (i) but not under (ii), the variance of w_{ft} conditional on functions of its past values does not depend on the conditioning factor. Thus under (ii) we have to use the conditional heteroskedasticity-robust instrumental variables technique (Hansen (1982) and White (1982)). Furthermore, under (i) we can use future values of y, Q and PAI as instruments. To see this we note from Proposition 2 that Q, and hence y and PAI, do not depend on the initial capital stocks. Thus current w_{ft}, while affecting current y_{ft}, Q_{ft} and PAI_{ft} and hence future capital stocks, does not affect y_{fs}, Q_{fs} and PAI_{fs} $(s > t)$. This is not true under (ii), because w_{ft} can change the second and higher moments of the distribution of w_{fs} $(s > t)$ and thus affect y_{fs}, Q_{fs}, and PAI_{fs} which are nonlinear functions of w_{fs}.

Therefore, under (i), the t-th equation (4.4) can be estimated by the standard 2SLS (two-stage least squares) with a set of instruments of past and future endogenous variables that do not overlap the time periods over which the first difference is taken, plus ten industry dummies:

$$(4.5) \qquad (Q_{f1},\ldots,Q_{f,t-1},Q_{f,t+2},\ldots,Q_{fT};\ y_{f1},\ldots,y_{f,t-1},y_{f,t+2},\ldots,y_{fT}; \\ PAI_{f1},\ldots,PAI_{f,t-1},PAI_{f,t+2},\ldots,PAI_{fT};\ IND_{f1},\ldots,IND_{f10}).$$

Under (ii), we can use only past values of instruments and have to allow for conditional heteroskedasticity, so that the t-th equation in (4.4) must be estimated by the heteroskedasticity-robust instrumental variables technique with a set of instruments of:

$$(4.6) \qquad (Q_{f1},\ldots,Q_{f,t-1};\ y_{f1},\ldots,y_{f,t-1};\ PAI_{f1},\ldots,PAI_{f,t-1};\ IND_{f1},\ldots,IND_{f10}).$$

Thus identification is achieved by the combination of the structure of the theory (summarized in Proposition 2) and the assumption about the temporal structure of the error term. Since the set of instruments differs across equations, the usual 3SLS (three-stage least squares) cannot be used to estimate the system of T-1 equations ((4.4) for t=1,...,T-1). We use Hansen's (1982) GMM (generalized methods of moments) estimator to carry out efficient "system" estimation that exploits the across-equation error correlation with or without conditional homoskedasticity.

5. RESULTS

Means and standard deviations of y (growth rate of the capital aggregate), Q (asset-aggregated tax-adjusted Q), and PAI (cash flow rate, corresponds to α in section 2) for the sample of 612 non-acquiring firms are reported in Table III. The cross-section variation of y is much smaller than that of Q, but the fact that it is larger than that of PAI suggests that measurement error may be more serious in the growth rate of the capital aggregate than in the level. That y and Q tend to move together over time is illustrated in Figure I which plots the mean of y against the mean of Q. Two notable exceptions are 1979-80 and 1985-86. In the 1979-80 period, when the real price of oil went up, y went up while Q declined. The opposite took place for the 1985-86 period when the real price of oil plummeted. This pattern is consistent with our parameterization of the growth-Q relation. If energy and capital are substitutes in that higher energy prices raise the demand for investment, then the intercept term a_t in (4.2) is an increasing function of energy prices.[17]

[17] The capital-energy complementarity issue has recently been reviewed by Solow (1987).

We first carry out the single-equation estimation of (4.4) for t = 1977, ..., 1985 under the serial correlation assumption (i) or (ii) of section 4. For each equation we calculate the Chi-square Hansen-Sargan J statistic for the set of over-identifying restrictions that there are more valid instruments than there are parameters to be estimated. For 2SLS, it equals:

$$(5.1) \qquad J_{homo} = N*\sigma^2*M(e_{ft}x_{ft}')M(x_{ft}x_{ft}')^{-1}M(x_{ft}e_{ft}),$$

where N here is the sample size, scalar e_{ft} is the residual for firm f in year t (which equals $w_{f,t+1}-w_{ft}$), σ is the standard deviation of the residual, x_{ft} is a column vector of instruments given by (4.5), and M(.) stands for the sample mean of its argument over f (= 1,...,N). For heteroskedasticity-robust 2SLS, it equals:

$$(5.2) \qquad J_{hetero} = N*M(e_{ft}x_{ft}')V^{-1}M(x_{ft}e_{ft}),$$

where x_{ft} now is a column vector of instruments given by (4.6), and V is the sample mean of the product of the residual and x_{ft}. To calculate V, which is an input to the calculation of the heteroskedasticity-robust 2SLS, we used the residual from 2SLS. Our findings are the following. (1) Except for 1981-82 and 1985-86, the set of over-identifying restriction is strongly rejected under homoskedasticity with instruments (4.5). If future endogenous variables are dropped from the list of instruments, the marginal significance under homoskedasticity is less than 3% for 1979-80, 1982-83, and 1983-84. (2) Under heteroskedasticity with instruments (4.6), we can easily accept the over-identifying restrictions except for 1979-80 where the marginal significance is 4%. (3) With instruments (4.6) we carried out the test of homoskedasticity suggested by White (1982, footnote 2) and corrected by Runkle (1989). The Chi-square test-statistic, which examines the correlation between the square of the error term and the cross products of fitted values of the right hand side variables, is guaranteed to be non-negative definite, but the weighting matrix turned out to be nearly singular in our data. (4) The heteroskedasticity-robust estimate of the Q coefficient with instruments (4.6) is significant for 1982-83 and 1985-86 at 1%. (If industry dummies are not included, the Q coefficient is significant at 5% for 1981-82 and 1984-85 also.) (5) If PAI is included in the equation (4.4) as the additional right hand side variable, the above results are not affected by much. Under heteroskedasticity and the instrument set (4.6), the PAI coefficient is significant at 5% only for 1982-83. If industry dummies are not included, the PAI coefficient is not significant for any period at 5%. (6) Industry dummies are for the most part insignificant and do not affect in any important way the parameter estimate of the Q and PAI coefficients except for the facts noted in (4) and (5).

Since the serial independence assumption (i) of section 4 is strongly rejected by the single-equation J statistic, we now focus on case (ii) (where w_{ft} is a martingale difference sequence) and carry out the joint GMM estimation under heteroskedasticity and with lagged instruments (4.6) where the Q coefficient is constrained to be the same across equations (years). We calculated the J statistic for the joint estimation, which also is the objective function to be minimized in the GMM (Hansen (1982)). It is written as:

(5.3) $$J_{joint} = N{*}M(h_f{}')V^{-1}M(h_f),$$

where $h_f{}' = (e_{f1}x_{f1}{}', \ldots, e_{f,T-1}x_{f,T-1}{}')$ and V here is $M(h_f h_f{}')$. The residual necessary for calculating V is taken from the heteroskedasticity-robust 2SLS. For the entire sample period, the set of over-identifying restrictions is strongly rejected, implying that the Q coefficient is not constant over time. The sharp increase in real factor prices that occurred in the 1979-80 period may have changed the second-order coefficient a_2 as well as the first-order coefficient a_1 in (4.1). Indeed, if we exclude this subperiod, there is no strong evidence against the cross equation equality restriction that a_2 is consant over time. The longest successive years for which the J statistic marginally significant at about 5% is 1981-86. Table IV reports parameter estimates for that period. The Q coefficient is fairly sharply estimated to be 0.02.[18] If PAI is included, its coefficient is also significant. Thus in the formal statistical sense the Q model can be rejected. The estimated PAI coefficient is about eight times as large as the Q coefficient, but the standard deviation of Q is about twenty times the standard deviation of PAI (see Table III). Thus Q still explains a much larger fraction of the cross section variation of the firm growth rate than PAI does. Table IV also has the serial correlation matrix of the residuals across equations (years) for the specification that excludes PAI (the correlation matrix for the specification with PAI in the equation is very similar). It accords with our assumption that $\{w_{ft}\}$ is serially uncorrelated and hence its first difference is a moving average process of order 1. Also reported in Table IV is the parameter estimates for the "conventional" specification where Q is q-1 and y is the ratio of the sum of nominal net investments to the sum of the end-of-

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[18] The estimate is robust with respect to the choice of instruments. We obtained very similar estimates when only lagged Q and industry dummies are used as instruments or when once lagged endogenous ($y_{f,t-1}, Q_{f,t-1}, PAI_{f,t-1}$) are dropped from the set of instruments. If we use the capital aggregate with the user cost of capital calculated under the assumption of perfect foresight about the next period's prices, the Q coefficient is .0085 (standard error: .00084), and when PAI is added to the equation the Q coefficient is .0078 (.00084) and the PAI coefficient is -.027 (.015). In both specifications the marginal significance for the J statistic is .000.

period capital stocks. The Q coefficient is now slightly higher,[19] but the set of over-identifying restrictions is strongly rejected.

The results so far is by and large favorable to the Q model. However, we obtained one apparently puzzling result which we now discuss. The parameter a_2 can alternatively be estimated from the first-order condition:

$$(5.4) \qquad Q_{ft} = a_1(p_{ft}) + a_2 y_{ft} + u_{ft},$$

with $a_1(p_{ft})$ represented by industry dummies. If the heteroskedasticity-robust joint GMM estimation with the same instrument set (4.6) is applied to (5.4), we obtain the following estimate (with the standard error in parentheses):

(5.5) y coefficient = 1.08 (.31), marginal significance of J = .000.

The estimate of a_2 is far smaller than the estimate of a_2 of about 50 implied by the Q coefficient reported in Table IV. The asymptotics does not seem to be working for us. This discrepancy may be explained by noting that the change in y is much more difficult to be instrumented than the change in Q is. We regressed the change in y, $y_{f,t+1}-y_{ft}$, on the instrument set (4.6) for each of the five years (t = 1981,..,1985). The R^2 on average is .09, while the R^2 for the change in Q regressions is .26 on average. Thus it seems that even with a fairly large sample like ours the y coefficient is hard to be estimated and that the small sample considerations would lead us to regard the reciprocal of the Q

[19] Note that our index of the capital aggregate Φ is normalized so that our Q equals q-1 for 1980. Thus the difference in the Q coefficient between the two specifications is not due to the difference in units. The Q coefficient in the conventional specification reported in Table IV is about seven times as large as the Q coefficient in a previous version of the paper. The difference is due to the fact that in the previous version we did not include land and inventories on the ground that adjustment costs may zero for land and inventories.

coefficient to be a more reliable estimate of a_2.[20]

Is our estimate of a_2 of about 50 implausibly large? Using the first order condition (5.4) we obtain the following expression for the sum of the first and second order terms of α:

$$(5.6) \qquad [a_1(p_{ft}) + u_{ft}]y_{ft} + (a_2/2)*(y_{ft})^2 = Q_{ft}*y_{ft} - (a_2/2)*(y_{ft})^2.$$

The mean over firms of this expression should not be too large relative to the mean of PAI which is the empirical counterpart of α. For 1981-86, the mean of Q*y is about 0.0448 and the mean of y squared is about 0.0124. Thus if a_2 is anywhere near 50, the mean of the second order term is far greater than the mean of PAI for 1981-86 of about .081.

To reconcile this with our belief that the reciprocal of the Q coefficient is a reasonable way to estimate a_2, we consider the case in which gross investment is measured with serially uncorrelated error. This brings about serially correlated measurement error in our capital stock measure, but since the capital stock is a weighted average of the stream of gross investment, the fraction of the cross section variation accounted for by measurement error is much smaller for the capital stock than for investment. Thus measurement error in y, the growth rate of the capital aggregate, will be dominated by the investment measurement error, which by assumption is serially uncorrelated, rather than by the capital stock measurement error. In fact, if measurement error were serious for the level of the capital aggregate, then cash flow rate PAI, whose denominator is the capital aggregate, would have a much larger standard deviation than is reported in Table III. The capital stock measurement error also contaminates

[20] Available estimates of the Q coefficient is very similar to ours. Blundell <u>et</u>. <u>al</u>. (1987) reports the Q coefficient of about 0.015.

Q. It gets magnified by the cross section variation in the true value of Q. Since the standard deviation of Q is ten to twenty times as large as that of y, measurement error in Q due to mis-measurement in the capital stocks can be in the same order of magnitude as the y measurement error. However, since the Q measurement error is further divided by a_2, the measurement error component of the error term in the growth-Q equation would be dominated by the serially uncorrelated y measurement error.

To get some idea about the size of the y measurement error, let us consider the case where the serially uncorrelated component of u_{ft}, w_{ft}, is entirely due to the y measurement error. The serial covariance of the first difference of w_{ft} has been reported in Table IV. If we assume that the variance of w_{ft} is constant over time, one half of the average over 1981-86 of the variances reported in the middle panel of Table IV is a good estimate of the variance of w_{ft}, which is about 0.0082.[21] So the measurement error in y accounts for about two-thirds of the cross section variation in y as measured by the mean of y squared of 0.0124, implying that the mean of the second-order term in (5.6) we calculated above must be divided by three. Even after this adjustment, the mean of the second-order term in (5.6) is still large relative to the mean of PAI, but now they are in the same order of magnitude. We therefore conclude that the estimated Q coefficient is still too small, but not as implausibly small as it first appears.

[21] The variance of the fixed effect v is about 0.0023. This is obtained as follows. Using the Q coefficient reported in Table IV, we calculate $y - Q/a_2$ which is regressed on the ten industry dummies for each year. The regression residual is an estimate of v_f+w_{ft}. The average of the variance of the regression residual over 1981-86 is about 0.0105. If one subtracts the variance of w_{ft} of 0.0082, one gets the estimate of the variance of v_f of 0.0023.

APPENDIX: DATA CONSTRUCTION

This appendix describes the calculation of the variables used in the estimation.

<u>Data Source</u> There are three primary data sources. For company financial statements data we use the tape compiled by the Japan Development Bank. We obtained share prices from the Nihon Keizai Shimbun's NEEDS database. The price index for output and investment goods are taken from components of the WPI (wholesale price index).

<u>Companies Selected</u> We selected from the financial statements file manufacturing companies that are listed on the Tokyo Stock Exchange in 1977 and that have continuous records until their 1986 fiscal year (the year ending between April 1986 and March 1986). This automatically eliminates companies that were acquired or ceased to be listed. Companies which changed the date of their year were also excluded. The data are then matched to the share price file, which yielded a balanced panel of 657 manufacturing companies.

<u>Output Price (OP)</u> This simply is the component of the WPI for the industry to which the company belongs. No attempt was made to obtain the breakdown of sales into commodities. The price index is at the beginning of the fiscal year and is normalized to unity for 1980.

<u>Price of Capital Goods (PK)</u> Assets (capital goods) are broken down into seven types: (1) nonresidential buildings, (2) structures, (3) machinery, (4) transportation equipments, (5) instruments & tools, (6) land, and (7) inventories. The price index for (1) and (2) is taken to be the construction material component of the WPI. The machinery component of the WPI has several subcomponents. We use the capital formation matrix of the 1975 Input-Output table by industry as the fixed weight to calculate the price index for machinery. The same procedure is used to construct the price index for instruments & tools. The transportation equipment component of the WPI is used as the price index for transportation equipments. We use the index of urban land prices compiled by the Japan Real Estate Research Institute for the price of land. The seventh asset, inventories, is further divided into (i) finished goods, (ii) goods in process, and (iii) raw materials. For finished goods, its price is OP. For raw materials we use the raw material component of the WPI. For goods in process, we use the simple average of the two. All the indexes are at the beginning of the fiscal year and are normalized to unity for 1980.

<u>Physical Depreciation Rates (δ)</u> For each of asset (3) and (4) we use the weighted average of the Hulten and Wykoff (1981) physical depreciation rates. As in the construction of the price indexes for investment goods, the fixed weights are obtained from the 1975 Input-Output table. Thus the depreciation rate for assets (3) and (4) differs across industries. The average over industries is 15.39% for machinery and 24.66% for transportation equipments. The depreciation rate for (5) is also taken from Hulten-Wykoff (1981) and equals 14.73%. For nonresidential buildings and structures, Dean, Darrow, and Neef (1987) report several estimates of the physical depreciation rate based on alternative aggregate investment series. We use the ones based on the Census

on Manufacturing investment series. The depreciation rate for nonresidential building is 4.7% and that for structures is 10.0%. For land and inventories, the depreciation rate is zero.

<u>Nominal Investment</u> For the first five assets, which are depreciable, calculation of nominal investment is complicated. We first establish the notation.

KGB_t = book value of gross capital stock at the beginning of year t,
KNB_t = book value of net capital stock at the beginning of year t,
AD_t = book value of accumulated depreciation at the beginning of year t,
DEP_t = accounting depreciation during year t,
ACQ_t = acquisition of assets during year t,
SR_t = acquisition value of assets that are sold or retired during year t,
$ADSR_t$ = book value of accumulated depreciation for assets that are sold or retired during year t,
NR_t = $SR_t - ADSR_t$, remaining book value of asset sold or retired,
CNR_t = our estimate of the replacement value of NR_t.

The items SR_t and $ADSR_t$ require some explanation. Let T be the asset life for tax purposes. Assets that were purchased T years ago "retire". SR_t is the acquisition value (with no allowance for depreciation) of those retiring assets <u>plus</u> the acquisition value of assets that are sold during year t. $ADSR_t$ is the accumulated depreciation on assets whose acquisition value is counted in SR_t. There is one complicating fact here about depreciation accounting. Suppose there is no sale of assets. For retiring assets that have been depreciated by the straight line method, NR_t is exactly zero. However, since the declining balance method leaves 10% of the acquisition value for the scrap value, for retiring assets that have been depreciated by the declining balance method, NR_t is 10% of SR_t.

As a matter of accounting identity, we have, for each asset type,

(A1) $$KGB_{t+1} = KGB_t + ACQ_t - SR_t,$$

(A2) $$AD_{t+1} = AD_t + DEP_t - ADSR_t,$$

(A3) $$KNB_t = KGB_t - AD_t.$$

The standard definition of nominal investment ($NOMI_t$) is

(A4)
$$\begin{aligned} NOMI_t &= KNB_{t+1} - KNB_t + DEP_t \\ &= KGB_{t+1} - KGB_t - (ADt+1 - AD_t) + DEP_t && \text{(by (A3))} \\ &= KGB_{t+1} - KGB_t + ADSR_t && \text{(by (A2))} \\ &= ACQ_t - (SR_t - ADSR_t) = ACQ_t - NR_t. && \text{(by (A1))} \end{aligned}$$

This definition of nominal investment has two problems. First, suppose there is no sale of assets. What we think of investment then is ACQ_t. If all assets have been depreciated by the straight line method, then $NR_t = SR_t - ADSR_t$ is zero and $NOMI_t$ in fact equals ACQ_t. But under the declining balance method $SR_t - ADSR_t$ is 10% of retiring assets. We can however expect this bias to be minor relative to ACQ especially when nominal investment is growing or (which is not the case in our sample) when the declining balance method is not the predominant method of depreciation. Second, if there is sale of assets, the term NR_t captures only the book value of the remaining value of assets sold.

Because of data availability, we computed $NOMI_t$ in three different ways depending on the sub-period of the data construction period. (1) Until the fiscal year ending September 1969, we only have KNB by assets and DEP aggregated over the five assets. (2) From October 1969 until March 1977, we have in addition KGB and AD by assets, and SR and ADSR aggregated over assets. (3) Since April 1977 we have all the items (especially the breakdown of DEP into the five assets) in (A4).

(1) From the first two successive fiscal years (which are after September 1969) for which AD_t is available, we can calculate the implied accounting depreciation rate $d = (AD_{t+1} - AD_t)/KNB_t$ for each asset. This is used as weights to distribute proportionately total depreciation between five assets. Until September 1969, $NOMI_t$ is calculated by the first line of (A4).

(2) From October 1969 until March 1977, we use the third line of (A4) to calculate $NOMI_t$ for each asset. To obtain a breakdown of total ADSR between assets, we assume that the ratio of $ADSR_t$ to AD_t is the same across assets.

(3) For the period since April 1977, we can address the two problems about NR_t mentioned above. The question is how to estimate CNR_t for each asset. If δ_B is the accounting depreciation rate and DS(x,t) is the fraction of assets acquired at year t that gets sold off x years later, NR_t and CNR_t are written as:

$$(A5)\qquad NR_t = \sum_{x=0}^{\infty} PK_{t-x}*D(x,t-x)*NOMI(t-x)*(1-\delta_B)^x,$$

$$(A6)\qquad CNR_t = \sum_{x=0}^{\infty} PK_t*D(x,t-x)*NOMI(t-x)*(1-\delta)^x.$$

This assumes that the declining balance method is used for depreciating all assets. The summation does not stop at x = T (asset life for tax purposes), to accommodate the 10% scrap value. If $\delta = \delta_B$ and if D(x,t) does not depend on t, then it can be easily shown that $CNR_t = NR_t*PK_t*K_t/KNB_t$, where K_t is the reproduction cost of capital calculated by the perpetual inventory method from the past stream of nominal investments to be explained below. For each asset, we use the last line of (A4) with NR_t replaced by CNR_t.

For land and inventories, their nominal investment can more conveniently explained in the next subsection.

Reproduction Cost of Capital (K) We carry out the perpetual inventory calculation for each asset. Let K_t = real capital stock at the beginning of year t, PK_t = price index at the beginning of year t, δ = physical depreciation rate. The perpetual inventory method is a recursion given by

$$(A7) \qquad PK_{t+1}*K_{t+1} = (1-\delta)*(PK_t*K_t + NOMI_t)*(PK_{t+1}/PK_t).$$

We initiated the perpetual inventory accounting in the base year of 1962 with the benchmark value for PK_t*K_t being the book value of capital at the end of the 1961 fiscal year. For companies that were started up after 1962, the base year is the year following the starting year. During the process of perpetual inventory accounting, we encountered negative K_t for some assets. In that event K_t is set at the book value.

For inventories, we categorize three inventory valuation methods: (1) FIFO, (2) Average method, (3) LIFO. Any other inventory valuation methods are forced to fall into either one of the three methods. For the inventories in other categories we simply take the book value to be the market value. The FIFO requires no inflation adjustment. The average method uses an average price for the inventories over the fiscal year to obtain the value at the end of the fiscal year. Our estimate of the market value of inventories under (2) takes into account the inflation during the fiscal year by applying to the book value the inflation factor which is the ratio of the price index at the end of the year to the price index averaged over the fiscal year. For the LIFO, we follow the standard LIFO recursion:

$$(A8) \qquad PK_{t+1}*K_{t+1} = \begin{cases} PK_t*K_t*(PK_{t+1}/PK_t) + (KB_{t+1} - KB_t) & \text{if } KB_{t+1} \geq KB_t, \\ PK_t*K_t*(PK_{t+1}/PK_t) + (KB_{t+1} - KB_t)*(PK_{t+1}/PK_t) & \text{if } KB_{t+1} < KB_t, \end{cases}$$

where KB_t is the book value at the beginning of year t. If a company uses more than one accounting method, we take the simple average of the market values calculated under the respective methods. This procedure is applied to finished goods, goods in process and materials. For any inventory accounting method, nominal investment is $NOMI_t = PK_t*(K_{t+1} - K_t)$.

For land, we use the following modification of the perpetual inventory method:

$$(A9) \qquad PK_{t+1}*K_t = PK_t*K_t*(PK_{t+1}/PK_t) + (KB_{t+1} - KB_t)*(PK_{t+1}/PK'_t),$$

where PK'_t is equal to PK_t if $KB_{t+1} - KB_t > 0$ and to PK for the year when KB increased most recently prior to t (this idea was borrowed from Hoshi and Kashyap (1987)). The choice of the benchmark is very important for land because the discrepancy between the market price and the acquisition price is great even in as far back as 1960. To obtain a factor that converts the book value into the market value, we look at the balance sheet for nonfinancial corporations in the National Income Accounts and the corresponding balance sheet in the <u>Corporate Statistics Annual</u> (Ministry of Finance). The former gives an estimate of the market value of land and the latter its book value for nonfinancial corporations as a whole. The earliest market value data in the National Income Accounts is at the end of 1969. The book-to-market value conversion factor is obtained by dividing the market value of land in the National Accounts data for 1969 by the book value in the Corporate Statistics Annual. The population of the nonfinancial corporate sector in the National Accounts differs slightly from that in the Corporate Statistics Annual. We use the difference in the book value of equity between the two data sources to adjust for the difference in the population. This adjusted conversion factor (which came out to be 7.582446) is applied to the 1969 book value of land of each company to get the benchmark market value of land. Nominal investment in land is $NOMI_t = PK_t*(K_{t+1} - K_t)$.

The Tax Rate (τ) There is a local corporate tax called the enterprise tax, whose rate we denote as v_t. Other corporate taxes include the national corporate tax, whose statutory rate is the same across regions, and the local corporate tax, whose rate depends on the company's address. If u_t is the combined rate for the corporate taxes other than the enterprise tax, it equals 1.207*(statutory national rate) if the company is located in specially designated regions and 1.173*(statutory national rate) otherwise. The enterprise tax rate v_t takes into account the regional variation depending on the location of the company headquarter. The enterprise tax paid this year is deductible from income next year. Thus the effective enterprise tax rate is lower than v_t. If this is taken into account, the "effective" corporate tax rate, τ_t, under static expectations about the interest rate and future tax rates is $\tau_t = (u_t+v_t)*(1+r_t)/(1+r_t+v_t)$, where r_t is a short term nominal interest rate. (See Hayashi (1985) for more details.)

Present Value of Tax Saving from Depreciation Allowance (A and z) Our calculation of z and A for each asset type differs from the standard procedure in the following respects. (1) We assume that companies can initiate write-offs in the year of purchase. (2) There is a tax break called the special depreciation. Companies can credit a certain fraction (s_{1t}) of new investment to a reserve called the special depreciation reserve. This is a "tax-free reserve" in that the amount credited is deductible from taxable income but that the same amount must be added back to income over a certain number of years TS (which we take to be ten years). This represents an implicit interest free loan granted by the tax bureau: the stream of repayment on a loan of one yen is 1/TS over TS years. Companies can also immediately write off a certain fraction (s_{2t}) of new investment and then apply the standard depreciation formula to the remaining value of investment. The ratio of the increase in the special depreciation reserves to ACQ_t is our estimate of s_{1t}. The amount of the second kind of special depreciation is identified as the excess of reported accounting depreciation over allowable depreciation. This is divided by ACQ_t to obtain s_{2t}. If D(x,t) is the formula for ordinary depreciation on asset of age x acquired in year t, the depreciation formula D'(x,t) incorporating the special depreciation is

$$\text{(A10)} \qquad D'(x,t) = \begin{cases} s_{1t} + (1-s_{2t})*D(x,t) + s_{2t} & \text{for } x = 0, \\ -s_{1t}/TS + (1-s_{2t})*D(x,t) & \text{for } x = 1,\ldots,TS, \\ (1-s_{2t})*D(x,t) & \text{for } x > TS. \end{cases}$$

(3) To calculate A, we need to know the stream of nominal investment prior to the start of the data construction period. Rather than "backcasting" the past stream of investment, we truncate the stream of investment at the start of the data construction period and at the same time substitute the book value of capital stock for the value of nominal investment for the first year.

The asset life for tax purposes is taken from Homma, Hayashi, Atoda and Hata (1984). It is highly aggregated and assumes the same value for machinery, transportation equipments, and instruments & tools. For z and A two values are calculated for the two depreciation method, the straight line and the declining balance methods. Other reported depreciation accounting methods are ignored. If the company reports both methods or neither methods, then the simple average of the two values is taken.

Financial Assets and Liabilities Except for stocks of affiliates held by the company, we did not try to convert book values into market values. Bank loans are the dominant component of long term debt in Japan. For the firms in the sample, we calculated the ratio of gross decrease in long term loans to the balance. Its average over the sample period ranges from 0.19 to 0.36, implying that the average maturity on long term loans is relatively short. Furthermore, long term debts (including bank loans) are about one half of short term debts. So for debts the discrepancy between the book value and the market value should not be important. The remaining issue is which balance sheet items should be recognized as assets and liabilities and how the affiliates's stocks should be valued. Financial assets includes: investments in affiliates, construction in progress, intangible fixed assets and differed charges. Some of the reserves on the balance sheet should be regarded as retention, not debts. We include all reserves except the so-called special reserves as part of gross debt.

Because the Japanese financial statements are not consolidated, the market value of affiliates's stocks (SAM) is a major component of financial assets. From the profit & loss statement we obtain the amount of dividend received from the affiliates stocks. If it is positive, then it is capitalized by the average dividend price ratio for all the dividend-paying stocks on the Tokyo Stock Exchange. This also gives an average of the ratio of the market value to the book value of affiliates stocks for all companies receiving positive dividends from affiliates. This ratio is used to convert the book value of affiliates stocks into a market value for companies receiving zero dividends.

Market Value of Equity This is simply the product of the share price and the number of shares outstanding. To account for the fact dividends are paid at the end of the fiscal year rather than at the start of the year, the equity value at the beginning of the fiscal year is multiplied by $1+r_t$ to arrive at the market value of equity.

Implicit Claims and Liabilities other than Depreciation Allowance Under the Japanese tax law there are a whole host of "tax-free reserves". Let R_t be the total amount credited to the tax-free reserves (other than the special depreciation reserve). This is the amount deducted from taxable income in the previous year. The same amount must be added back to current taxable income. Thus the tax-free reserves represents an interest-free one year loan granted by the government. Some of the tax-free reserves are accruals and others are retention in nature, but they all represent interest-free loans. It is not possible from the financial statements provided in the Japan Development Bank file to identify all the tax free reserves, because some of the minor tax-free reserves are merged with non tax-free reserves on the balance sheet. We assume that all the so-called special reserves are tax-free reserves. Main components of R_t other than the special reserves are the accrued employees' severance indemnities (retirement reserve) and the allowance for bad debts. For most tax-free reserves, as far as we can tell from the tax code, the amount credited must be added back to the next year's income in full (the notable exception being the special depreciation account, which represents a long term tax-free loan, as we noted above, and which is already incorporated in A_t through s_{1t} in (A10)). We assume that this is the case for all tax-free reserves (except for the special depreciation reserves). Then τ_t*R_t represents the amount owed to the government in year t. On the other hand, since the amount of enterprise tax paid in the previous year (ENT_t) is deductible from income, there is an invisible claim of τ_t*ENT_t. The market value of implicit claims, mentioned in Table I, equals τ_t*(ENT_t - R_t). For more conceptual details, see Hayashi (1985).

Ten Industry Classification The ten manufacturing industries underlying the industry dummies are the following: (1) food, (2) textile, (3) paper, (4) chemical, (5) primary metal, (6) metal products, (7) machinery, (8) electrical appliances, (9) transportation equipments, and (10) other. This classification is the one adopted in Homma, Hayashi, Hata and Atoda (1984).

REFERENCES

Blundell, R., S. Bond, M. Devereux, and F. Schiantarelli (1987): "Does Q Matter for Investment? Some Evidence from a Panel of UK Companies", mimeo., Institute for Fiscal Studies Working Paper No. 87/12.

Chirinko, R. (1983): "Tobin's Q with Multiple Capital Goods", mimeo.

Dean, E., M. Darrow, and A. Neef (1987): "Alternative Measures of Capital Inputs in Japanese Manufacturing", mimeo.

Fazzari, S., R.G. Hubbard, and B. Petersen (1988): "Investment and Finance Reconsidered"; Brookings Papers on Economic Activity, 1988:1.

Hansen, L. (1982): "Large Sample Properties of Generalized Methods of Moments Estimators", Econometrica, 50, 1029-1054.

Hayashi, F. (1982): "Tobin's Marginal q and Average q: A Neoclassical Interpretation", Econometrica, 50, 215-224.

Hayashi, F. (1985): "Taxes and Corporate Investment in Japanese Manufacturing," National Bureau of Economic Research Working Paper No. 1753.

Homma, M., F. Hayashi, K. Hata, and N. Atoda (1984): Corporate Investment and Taxes (in Japanese), Economic Research Institute Monograph No. 41, Economic Planning Agency of the Japanese Government.

Hoshi, T., and A. Kasyap (1987): "Evidence on q for Japanese Firms", mimeo.

Hulten, C., and C. Wykoff (1981): "The Measurement of Economics Depreciation", in: C. Hulten ed., Depreciation, Inflation and the Taxation of Income From Capital, Urban Institute.

Jorgenson, D. (1986): "Econometric Methods for Modelling Producer Behavior", in Griliches, G. and M. Intriligator eds., Handbook of Econometrics, volume 3, Amsterdam: North-Holland, 1841-1915.

Lucas, R. and E. Prescott (1971): "Investment under Uncertainty", Econometrica, 39, 659-681.

Poterba, J. and L. Summers (1983): "Dividend Tax, Corporate Investment and 'Q'", Journal of Public Economics, 22, 247-273.

Runkle, D. (1989): "Diagnostic Tests for Linear Rational Expectations Models", mimeo., Federal Reserve Bank of Minneapolis, March 1989.

Solow, J. (1987): "The Capital-Energy Complementarity Debate Revisited", American Economic Review, 77, 605-614.

Summers, L. (1981): "Inflation, Taxation and Corporate Investment: A Q Theory Approach", Brookings Papers on Economic Activity, 1981:1, 67-127.

Wildasin, D. (1984): "The q Theory of Investment with Many Capital Goods", American Economic Review, 74, 203-210.

von Furstenberg, G. (1977): "Corporate Investment: Does Market Valuation Matter in the Aggregate?", Brookings Papers on Economic Activity, 1977:2, 347-397.

White, H. (1982): "Instrumental Variables Regression with Independent Observations", Econometrica, 50, 483-500.

TABLE I

MARKET VALUE OF BALANCE SHEET ITEMS[a]

item	77	78	79	80	81	82	83	84	85	86
Assets										
fin. assets excluding stocks of affiliates	47679	48491	50760	56246	58915	64521	66110	71416	76724	76487
stocks of affiliates	8600	12076	14220	17535	19797	22696	27514	36625	45513	52963
nonresidential bldg.[b]	7362	7245	7680	9425	9010	8939	9041	9055	9207	9127
structures[b]	1778	1816	1906	2317	2129	2043	2001	1937	1886	1754
machinery[b]	7731	7308	7082	7782	7722	8054	8420	8491	9044	9017
transp. equipments[b]	80	88	89	98	96	102	99	95	97	92
instruments & tools[b]	1289	1254	1385	1884	1797	1938	2097	2260	2530	2705
land	22079	22773	23900	26129	28761	31120	32926	34388	35664	37152
inventory	17618	16496	16249	21150	21813	23699	23008	22850	24182	21294
present value of tax savings due to depreciation[c]	3175	3260	3042	2764	3231	3762	4298	5002	5534	6266
Liabilities										
gross debt (book value)	70176	70789	71362	78175	82502	88156	90068	94180	98880	97464
equity	35339	36662	44866	49192	61673	65051	76234	101672	107720	119281
tax-adjusted Tobin's q[d]	0.795	0.766	0.827	0.739	0.872	0.820	0.881	1.047	0.954	0.999
tax-adjusted Tobin's q[e]	1.019	1.012	1.270	1.007	1.151	0.967	1.036	1.563	1.580	1.630

[a] Averages over 614 Japanese non-acquiring manufacturing firms, in million yen.
[b] These are valued at tax-adjusted prices (1-z)*PK. For land and inventories, z = 0.
[c] This item corresponds to the A_t in equation (2.3). It also includes the market value of implicit loans granted by the government through the "special depreciation" and "tax-free reserves" provisions of the Japanese tax code.
[d] The tax-adjusted Tobin's q is defined by (2.20). This is the ratio of averages.
[e] The average of individual tax-adjusted Tobin's q ratios.

Table II

POOLED OLS ESTIMATE OF THE GROWTH-Q RELATION[a]

constant	Q	PAI	s.e.r.	R^2	sample size
0.017 (0.0014)	0.015 (0.00096)	-------	0.108	0.037	6140
-0.018 (0.0022)	0.0079 (0.00099)	0.37 (0.018)	0.104	0.101	6140

IN FIRST DIFFERENCES

constant	$Q-Q_{-1}$	$PAI-PAI_{-1}$	s.e.r.	R^2	sample size
0.0014 (0.0018)	0.016 (0.0018)	-------	0.133	0.014	5526
0.0012 (0.0018)	0.016 (0.0019)	0.066 (0.037)	0.133	0.014	5526

[a] The panel of 614 non-acquiring firms are pooled across years. Standard errors in parentheses.

TABLE III

MEANS AND STANDARD DEVIATIONS (SAMPLE SIZE IS 614)

year	y		Q		PAI	
	mean	std. dev.	mean	std. dev.	mean	std. dev.
1977	-0.0114	0.109	0.0231	0.755	0.0742	0.078
1978	-0.0016	0.121	0.0030	0.793	0.0912	0.074
1979	0.0128	0.116	0.2468	1.007	0.1129	0.079
1980	0.0215	0.097	0.0066	0.828	0.1033	0.073
1981	0.0242	0.113	0.1400	1.058	0.0998	0.085
1982	0.0147	0.117	-0.0482	0.998	0.0939	0.083
1983	0.0362	0.108	0.0106	1.319	0.0981	0.081
1984	0.0512	0.106	0.5553	1.964	0.1127	0.082
1985	0.0421	0.091	0.5833	2.111	0.1068	0.077
1986	0.0110	0.103	0.6451	2.153	0.1025	0.081

TABLE IV

JOINT ESTIMATION, 1981-86[a]

coefficient estimate for Q	PAI	marginal significance of J_{joint}
.020 (.0035)	------	.048
.020 (.0035)	.16 (.064)	.090

cross-equation correlation of residuals[b]

	81-82	82-83	83-84	84-85	85-86	variance
81-82	1.00					0.02112
82-83	-.54	1.00				0.02068
83-84	.01	-.46	1.00			0.01634
84-85	.02	-.06	-.45	1.00		0.01422
85-86	-.01	-.05	-.08	-.21	1.00	0.00969

"conventional" specification[c]

coefficient estimate for Q	PAI	marginal significance of J_{joint}
.027 (.0026)	------	.000
.026 (.0027)	.18 (.059)	.000

[a] Sample size is 614. Coefficients of industry dummies are not reported. Standard errors in parentheses.

[b] Calculated from the specification that excludes PAI.

[c] y here is the ratio of the sum of nominal net investments to the sum of the end-of-period capital stocks, and Q is q-1 where q is Tobin's tax-adjusted q defined in (2.20).

List of symbols

A: present value of depreciation allowances on assets already acquired (see (2.3))
a_0: intercept in the profit function α (4.1)
a_1: first-order coefficient in the profit function (4.1)
a_2: second-order coefficient in the profit function (4.1)
b: industry dummy coefficients (4.3)
DEP: accounting depreciation (2.1)
e: generic notation for the error term used in section 5
F: profit function (2.1)
f: index for firms
h: product of the residual and instruments (5.3)
I: gross investment (2.1)
i: index for capital goods
IND: industry dummies (4.3)
J: user cost of capital (2.9)
K: initial capital stock (2.1)
M: sample mean (5.1)
N: net investment ((2.1) or (2.2))
m: macro component of the error term (4.3)
n: number of capital goods
OP: output price (2.1)
p: real price of variable factor inputs (2.1)
PAI: cash flow rate, ratio of cash flow (earnings plus accounting depreciation less income taxes) to $(1-\tau_t)*OP_t*\Phi(K_{t+1})$, equals α of section 2
P_Φ: implicit price index of the capital aggregate (2.21)
PK: price of investment goods (2.1)
Q: asset-aggregated tax-adjusted Q ((2.16) or (2.19))
Q_i: asset-specific shadow price (2.6)
q: tax-adjusted Tobin's q (2.20)
r_i: real rate of return on asset i (3.3)
s: state of the world
T: length of the panel
u: shock to the profit function (2.1)
V: value of the firm (2.1)
v: firm-specific component of the error term (4.3)
W: value of the firm at tax-adjusted prices ((2.3) or (2.4))
w: serially uncorrelated component of the error term (4.3)
x: generic notation for the vector of instruments used in section 5
y: growth rate of the capital aggregate (2.14)
z: present value of accounting depreciation on a dollar of investment (2.4)
α: profits per unit of the capital aggregate (2.13)
$\beta_{t,j}$: discounting factor for a j-period ahead payoff at t (2.1)
$\beta_{R,t}$: one-period real discount factor (2.10)
δ_i: physical rate of depreciation of asset i (2.1)
Φ: capital aggregate (2.13)
π: idiosyncratic component of the error term in (4.2)
σ: standard deviation of the residual
τ: "effective" tax rate (2.1)