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Author(s): Robert S. Chirinko

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Business Fixed Investment Spending: Modeling Strategies, Empirical Results, and Policy Implications

By ROBERT S. CHIRINKO
University of Illinois and
Federal Reserve Bank of Kansas City

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I. *Introduction and Overview*

> Economics has then as its purpose firstly to acquire knowledge for its own sake, and secondly to throw light on practical issues. (Alfred Marshall 1920, p. 33)

THE PACE AND PATTERN of business investment in fixed capital are central to our understanding of economic activity. The considerable volatility of investment expenditures is a prime contributor to aggregate fluctuations. Periodic reports of "capital shortages" link insufficient business investment to a host of economic ills. Reduced long-run growth in industrialized economies and stubbornly high unemployment in Europe have been attributed to anemic investment expenditures. That new investment may generate learning externalities or be the leading channel through which innovations stimulate growth has led to much interest in public policies encouraging fixed capital formation.

Investment behavior has thus been an important topic on the economic research agenda for some time. The successes, failures, and empirical results from that literature are reviewed critically in this survey. While there have been many different approaches to understanding investment spending, researchers have encountered repeatedly the following four issues:

1) consistency of the theoretical model,
2) characteristics of the technology,
3) treatment of expectations, and
4) the impact on investment spending of prices, quantities, and shocks.

The way in which these issues are addressed by the various modeling strategies forms the first organizing principle of the survey. These four issues emerged in sharp relief in the extensive body of work with Jorgenson's Neoclassical Model. Following that program, investment researchers have relied increasingly on formal models that, in large part, have been developed in response to these recurring problems. While the first three have been addressed in a reasonably satisfactory manner, formal models have been less successful in empirical implementation and hence in providing insights into the determinants of investment spending.

Consideration of the manner in which dynamics are incorporated into econometric models forms the second organizing principle. Dynamics have been central to developments in economics during the past two decades, and econometric models of nonresidential business fixed investment (hereafter referred to as "investment") offer a particularly useful lens for appreciating the strengths and shortcomings of this work. The numerous models appearing in the investment literature are divided into two broad categories depending on whether dynamics are treated implicitly or explicitly. Models are included in the latter category if dynamic elements appear explicitly in the optimization problem and if the estimated coefficients are linked explicitly to the underlying technology and expectation parameters. The Implicit category contains those investment models that do not meet these criteria. This dichotomy is also useful because, to a first approximation, it separates the Implicit models examined in the 1971 *Journal of Economic Literature* survey by Dale Jorgenson from the Explicit models developed subsequently.

The Implicit and Explicit models are discussed in Sections II and III, respectively. Benchmark models are presented for each of these categories, and are quite simple, relying on no more than recognizing the fundamental relation between optimal behavior and the equality of expected benefits and costs at the margin. For each model within a category, the underlying theory, key assumptions and caveats, and available empirical results are reviewed. In order to present a comprehensible survey, the text contains the primary results, and a number of important points and citations are placed in the footnotes. Nonetheless, many useful references and details are omitted, and a longer version of the survey, as well as an extended bibliography, are available as a monograph (Chirinko forthcoming a). Regarding empirical results, the survey restricts its focus to the prominent and enduring tension concerning the relative importance of price variables (taxes and interest rates), quantity variables (output and liquidity), and autonomous shocks ("animal spirits" and technology shocks) as determinants of investment spending.

Part of the excitement in working in the investment area is that the theoretical models and empirical results also stimulate and inform policy discussions. Apart from new explicit econometric frameworks, an important development over the past 20 years has been a widening gap between those who develop and test models and those who actively use them in policy and business applications. Currently, there exist two largely noninteracting groups of economists studying investment spending. Section IV examines the relation between this schism and the important critique advanced by Robert Lucas, as well as the latter's impact on modeling strategies and "practical issues."

The discussion of the Lucas Critique serves as a transition between the historical review in Sections II and III and some of the important topics on the research agenda discussed in Section V. The survey concludes in Section VI that future research should be undertaken with Explicit models and should be directed toward a more general understanding of business behavior and the many margins along which firms operate.

II. *Models with Implicit Dynamics*

> While widely and variously used, most distributed lag models have almost no or only a very weak theoretical underpinning. Usually the form of the lag is assumed *a priori* rather than derived as an implication of a particular behavioral hypothesis. (Zvi Griliches 1967, p. 42)

> Economic theory is practically silent on the form of particular dynamic economic relationships. (Lawrence Klein 1974, p. 46)

This section reviews models in which the dynamic elements affecting the econometric specification do not follow explicitly from the firm's optimization problem. A Benchmark Model is developed that serves as a basis for interpreting these Implicit models. With this Benchmark Model in hand, we begin the survey with a highly selective review of the Neoclassical Model and criticisms thereof that were crucial in defining the investment research agenda and stimulating subsequent developments.[1] The Vector Autoregressive, Effective-Tax-Rate, and Return-Over-Cost models developed in the 1980s are also examined.

A. *The Benchmark Model*

The Benchmark Model is based on a demand for capital and, with the addition of dynamics, a demand for investment. The demand for capital is derived from elementary economic principles, and is determined by the equality between the expected marginal benefits and costs from an additional unit of capital. This equality can be transformed so that the desired (or optimal) capital stock (K_t^*) depends on price variables, quantity variables, and autonomous shocks,

$$K_t^* = f\,[\text{prices, quantities, shocks}]. \qquad (1)$$

Equation (1) follows from well known static theory and, absent any dynamic considerations, the firm would achieve K_t^* instantaneously. Dynamics are introduced into the Benchmark Model when specifying the demand for the flow of investment and, "rather than derived as an implication of a particular behavioral hypothesis," dynamics are imposed implicitly. The Benchmark Model depends on two types of dynamics. First, the translation from a stock demand to a flow demand is based on a series of maintained assumptions about 1) delivery lags (as well as expenditure and gestation lags), 2) adjustment costs, 3) vintage effects (i.e., the putty and clay qualities of capital), and 4) replacement investment. These dynamic elements may compel the firm to look deep into the future. The firm's expectations, however, are usually unobservable to the applied researcher. A second set of dynamics is introduced when these unobservable expectations are linked to observable variables through regressive or extrapolative schemes represented by distributed lags. As we shall see, the various combinations of assumptions concerning the desired

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[1] Reviews of the early literature can be found in John Meyer and Edwin Kuh (1957, ch. 2), Eisner and Robert Strotz (1963, ch. 3), Jorgenson (1971), and Chirinko (forthcoming a).

capital stock (1), expectations, and the other dynamic elements listed above define the different Implicit models appearing in the literature.

B. *Neoclassical Models*

Theory. By far the most frequently used specification for the analysis of investment spending has been the Neoclassical Model pioneered by Jorgenson and his numerous collaborators (Jorgenson 1971). Prior to the "Neoclassical Revolution," no rigorous framework existed for investigating the determinants of investment, especially the effects of relative prices.[2] In this model, the firm maximizes the discounted flow of profits over an infinite horizon, delivery lags, adjustment costs, and vintage effects are absent, and capital depreciates at a geometric rate. As a consequence of these assumptions, the firm can achieve any K_t^* instantaneously. Thus, the firm does not need to take a deep look into the future, and the multiperiod optimization problem becomes essentially static.[3] Maintaining that the production function has a constant elasticity (σ) of substitution between capital and variable inputs, we obtain the following well-known relation between the desired stock of capital, the level of output, and the user cost (or rental price) of capital (C_t),

$$K_t^* = \alpha\, Y_t\, C_t^{-\sigma}, \tag{2a}$$

$$C_t = p_t^I(r_t + \delta)\,(1 - m_t - z_t)\,/\,(1 - t_t), \tag{2b}$$

where α is the distribution parameter, p_t^I is purchase price of new capital (relative to the price of output), r_t is the real financial cost of capital net of taxes, δ is the geometric rate of capital depreciation, m_t is the rate of the investment tax credit, z_t is the discounted value of tax depreciation allowances, and t_t is the rate of business income taxation. Equation (2a) highlights the dependence of the desired capital stock on a quantity variable (Y_t) and a set of price variables (p_t^I, r_t, and taxes) combined in the user cost.

To form an investment relation, we divide total investment into net and replacement components. Net investment (I_t^n) is determined by a distributed lag on new orders, which equal in a given period the change in the desired capital stock,

$$I_t^n = \sum_{j=0}^{J} \beta_j\, \Delta K_{t-j}^*, \tag{3}$$

where the β's represent the delivery lag distribution extending for $J + 1$ periods. Capital is assumed to depreciate geometrically at a constant mechanistic rate (δ). Replacement investment (I_t^r) is proportional to the capital stock available at the beginning of the period and, in contrast to I_t^n, adjusts instantaneously,

$$I_t^r = \delta K_{t-1}. \tag{4}$$

Combining (2), (3), and (4) and appending a stochastic error (u_t), we obtain the Neoclassical Model of investment,

$$I_t = I_t^r + I_t^n = \delta K_{t-1} + \sum_{j=0}^{J} \alpha\, \beta_j\, \Delta(Y_{t-j} C_{t-j}^{-\sigma}) + u_t. \tag{5}$$

While the dynamics associated with replacement investment follow from explicit assumptions, theory has been "practically silent" on the distributed lag coefficients for net investment. In Jorgenson's work, σ was always assumed to be unity, though alternative values are

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[2] A role for prices, as well as shocks, was introduced informally in *The General Theory*, where the benefits and costs of acquiring capital were related to the marginal efficiency of capital (i.e., internal rate of return, affected substantially by autonomous shocks) and the interest rate, respectively (John Maynard Keynes 1936, pp. 135, 165).

[3] The only dynamic element remaining is the expected one-period inflation rate in output, capital goods, or share prices needed to convert nominal to real rates in r_t.

also consistent with the Neoclassical framework (Eisner and M. Ishaq Nadiri 1968). When $\sigma = 0$, (5) reduces to the flexible accelerator (Hollis Chenery 1952) and, if delivery lags are absent, the simple accelerator (John Clark 1917). In these cases, fiscal and monetary policies, operating through C_t, can have no direct effect on investment or the desired capital stock, but may have indirect effects through Y_t.

Four Key Issues. Estimated equations based on variants of (5) have appeared frequently and, as with any pioneering effort, have been subject to a number of criticisms. These are reviewed briefly, and are related to the four recurring issues in investment research listed in Section I.[4]

The initial set of criticisms pertains to the consistency of the theoretical model, and there have been three specific problems. First, the profit-maximizing firm chooses the capital stock, other factors of production, and output simultaneously. Equations (2) or (5) do not usually recognize these interactions nor, as discussed frequently in the literature, the dependence of the optimal level of output on the user cost.[5] Regarding the latter point, even if the endogeneity of output does not bias the estimated coefficients (discussed in Section II.C), simulations based only on (5) will underestimate the effects of policies intended to stimulate capital formation.

Second, the development of (5) was based on an inharmonious treatment of delivery lags. The optimal capital stock (2) was derived under the assumption that delivery of capital goods was immediate, but the net investment equation (3) was based on a delivery lag distribution. In this formulation, the investment path generated by the Neoclassical Model may not be optimal—see John Gould (1969) and Marc Nerlove (1972), and the response by Jorgenson (1972). However, under static expectations (as assumed by Jorgenson), the model is consistent because the benefits and costs of acquiring capital are expected to be the same at any point in time, hence independent of any delivery lag.

Third, the definition of K_t^* provided by (2) has been questioned. No problem arises if the production technology exhibits decreasing returns to scale but, when returns are constant (as assumed by Jorgenson), K_t^* is not well defined. In this case, Jorgenson (1972, p. 246) has argued that

> desired capital should be interpreted as a moving target rather than the long-run equilibrium value of capital. . . . This policy is identical to that appropriate for a description of technology with production and installation subject to constant returns to scale.

As with the analysis of delivery lags, such an interpretation depends crucially on static expectations. Relaxing this assumption and specifying the theoretical model explicitly were items that remained on the investment research agenda.

The second set of criticisms concerns the characteristics of the technology, and three aspects have been discussed. First, vintage effects may influence the relation between past investments and the capital stock entering the production function. Under one specification, vintage effects are absent if capital is putty-putty—both before and after installation, it can be combined with other inputs in any desired proportions. This assumption is used in most investment studies, and implies that the period in which capital is purchased is of no particular importance. At the opposite extreme, vintages matter

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[4] Additionally, each component of C_t has been the subject of controversy, and each is reviewed in Chirinko (forthcoming a). Of particular concern has been the role of taxes in r_t; see Sinn (1991) for a recent discussion.

[5] For exceptions, see the Implicit models developed by Nadiri and Rosen (1973), Robert Coen and Bert Hickman (1970), and Frank Brechling (1975).

if capital is putty-clay—before installation, it can be combined with inputs in any desired proportion (which depends on the path of input prices expected at the time of acquisition); however, after installation, the proportion is fixed until the capital good is retired. Consequently, output changes lead to more rapid investment than comparable (with respect to K_t^*) user cost changes, and (5) must contain separate distributed lags for the output and user cost terms.

Second, the Neoclassical Model assumes that capital depreciates at a constant geometric rate, thus justifying the treatment of replacement investment as a fixed proportion of the existing capital stock. The validity of constant geometric depreciation has been the subject of numerous empirical investigations providing mixed support for this assumption.

Third, an additional aspect of the technology that has generated significant controversy is the value of σ. This parameter is both the elasticity of substitution between labor and capital and the elasticity of K_t^* with respect to C_t, which contains all of the price terms. Thus, in the original version of the Neoclassical Model (5), the potency of tax policies and interest rates, ceteris paribus, is closely linked to the value of σ. However, this critical role for σ depends heavily on static expectations. In the presence of nonstatic expectations and delivery lags, the terms in (2a) would be distributed over current and future periods and interpreted as expected values.[6] Approximating K_t^* linearly and assuming that expectations of the output and user cost terms are based on extrapolations of their past values, we obtain the following modified Neoclassical Model,

$$I_t = \delta K_{t-1} + \sum_{j=0}^{J_y} \alpha \gamma_{Y,j} \Delta Y_{t-j} - \sigma \sum_{j=0}^{J_c} \alpha \gamma_{C,j} \Delta C_{t-j} + u_t. \quad (6)$$

As shown by (6), knowledge of σ alone does not determine the response of investment to the user cost.[7] Rather, the estimated distributed lag coefficients represent an amalgam of delivery lag and expectation parameters (γ's), as well as production function parameters.

In the above discussion and elsewhere, expectations play a crucial role in investment decisions. Static or extrapolative expectations are assumed in versions of the Neoclassical Model, but are totally at odds with the fundamental forward-looking nature of capital accumulation. This treatment of expectations has led to the third set of important criticisms that are related to the "Lucas Critique" discussed in Section IV.

The fourth and final issue concerns the relative importance of prices, quantities, and autonomous shocks as determinants of investment spending. There has been much debate involving the former two variables that hinges on, among other issues, the manner in which ΔY_t and ΔC_t enter the regression. This sensitivity is highlighted by the diversity of results from papers presented at a Brookings Conference. Robert Hall and Jorgenson (1971) enter output and user cost as a composite term. Charles Bischoff (1971) presents a putty-clay model where σ is estimated freely and found to be close to unity. Coen (1971) estimates a model with separate distributed lags for output and user cost. With their estimated equations, the authors quantify in a partial equilibrium setting the added investment resulting from the tax depreciation change in 1954. For 1954–1962, Hall and

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[6] Because this alternative derivation depends on nonstatic expectations, it is plagued by an inconsistent treatment of delivery lags in the optimization problem.

[7] However, this parameter does determine the response of K_t^* to C_t in the long run, provided K_t^* is well defined.

Jorgenson's Neoclassical Model (similar to (5)) implies that, on average, investment was raised 6.89 percent. This estimate is due largely to the effects of output on investment that are embedded in the composite term. When ΔY_t and ΔC_t enter separately in models that resemble (6), the response to the tax change is much lower. In Bischoff's putty-clay framework, the comparable response is 1.46 percent. Coen finds that investment was higher by either 3.87 percent or 2.02 percent, the latter result obtained when cash flow affects the speed with which firms adjust to changes in K_t^*. These results exemplify the general tendency found in other studies that, relative to the user cost, output has a more substantial impact on investment.

Although these and other empirical results with versions of the Neoclassical Model differ widely, they suggest to this author that output (or sales) is clearly the dominant determinant of investment spending with the user cost having a modest effect. Before proceeding to models with explicit dynamics in Section III, we examine some other Implicit models developed in the 1980s that address the role of autonomous shocks and provide additional evidence on the relative strength of prices and quantities.

C. *Some Recent Implicit Models*

Vector Autoregressive Models. Autonomous shocks can play an important role in assessing the determinants of investment. While estimation issues receive little attention throughout the survey, we note here that reported empirical results could be affected seriously by a simultaneity problem induced by autonomous shocks contained in u_t. For example, in the Neoclassical Model, these shocks could be correlated positively with both ΔY_t and ΔC_t in (5) because of technology shocks interacting with the joint endogeneity of firm decisions or because of links between aggregate saving and investment. The resulting bias could account for the finding of significant output effects and insignificant user cost effects, even though the latter has a substantial negative impact on investment. Instrumental variables is the appropriate econometric technique for addressing this problem, but obtaining valid instruments is a difficult task.

Further obstacles to identification of structural parameters occur because variables—with no direct impact on investment but useful in forming expectations—may enter significantly or because a predetermined variable in the econometric equation may have multiple interpretations. As an example of the latter problem, capital depreciation was assumed to be a technological constant in the Neoclassical Model, yet this rate may well be variable and determined by interest rates and the level of or change in output. In this case, it is difficult to identify the coefficients on ΔY solely with the delivery lag technology—cf. (6). For any of these reasons, structural interpretations are blurred, and identification may be compromised.

In response to these potential problems, Christopher Sims (1980) argues for a relatively nonstructural approach.[8] Believing that the restrictions needed to identify the econometric structure are "incredible," Sims treats each variable in the system as endogenous, and regresses current values on their own lags and those of all other variables in the system. In this Vector Autoregression (VAR), the dynamics are implicit.[9]

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[8] See Edmond Malinvaud (1981) and Thomas Cooley and Stephen LeRoy (1985) for critical reviews of VARs, and Charles Bean (1981), Bosworth (1985), and Alan Auerbach and Kevin Hassett (1991) for alternative nonstructural approaches.

[9] An entirely different interpretation of VARs has been advanced by Sims (1982), who argues that, rather than belonging to the Implicit category, VARs can be interpreted as the logical extension of the explicit modeling strategy to be considered in Sections III and IV.

Only a few authors have applied this approach to investment spending. Based on their hybrid VAR, Robert Gordon and John Veitch (1986) find that ΔY, C, and q (to be introduced in Section III.B) are not important determinants relative to the real money stock and that nonresidential structures are heavily influenced by autonomous shocks. In contrast, W. Douglas McMillin (1985) for the United States and Michael Funke (1989) for West Germany report that q has important effects on investment and that money and government debt affect investment only through q.

Effective-Tax-Rate Models. Martin Feldstein's (1982) Effective-Tax-Rate Model relates net investment directly to a quantity and a price variable, and is of particular interest because it provides an alternative way of examining the effects of taxes on investment. The price variable, RN_t, is the net real return to capital, and is defined as the average yield to bondholders and equity holders net of depreciation and effective taxes. The latter is a comprehensive measure of taxes affecting the ultimate providers of funds. The quantity variable captures fluctuations in demand, and is measured by an index of capacity utilization, $UCAP_t$. Dynamics enter by lagging both the price and quantity variables one period to reflect delays in decision making, production, and deliveries and to avoid simultaneity bias. These considerations, coupled with a stochastic error term, lead to the following specification of the Effective-Tax-Rate Model,

$$I_t^n/Y_t = \gamma_0 + \gamma_1 RN_{t-1} + \gamma_2 UCAP_{t-1} + u_t, \quad (7)$$

where the dependent variable is scaled by output presumably to account for the trend component in the investment series and to place all variables in the same units. If expectations are assumed to be static, then the γ's represent only the technology. If expectations are extrapolative, then, as with the alternative derivation of the Neoclassical Model (6), the coefficients in (7) represent a combination of expectation and technology parameters.

There are two important differences between the Neoclassical and Effective-Tax-Rate models. First, the price variable in the Neoclassical Model (C_t) is defined as a marginal concept, while RN_{t-1} is based on averages.[10] Neither would appear to be dominant in the analysis of capital formation incentives. Average returns are a deficient measure because they are not directly related to the marginal decisions at the core of economic theory. However, quantifying the marginal benefits and costs of capital can be achieved only by considering selected features of the tax code and by relying on a number of maintained assumptions—competitive markets, uniformly positive taxable profits, and the maximization of a particular objective function constrained by a particular technology. Studies using average returns are best viewed as complementary to work with marginal concepts where, in the former, potentially restrictive assumptions are relaxed at the expense of a direct link to a well-specified model of capital accumulation.

Second, unlike the two-stage procedure in the Neoclassical Model, the Effective-Tax-Rate Model relates net investment directly to quantity and price variables, thus treating "the combined behavior of firms and households as a 'black box' that links net investment to the net-of-tax profitability of investment" (Feldstein 1987a, p. 391). Nonetheless, (7) can be interpreted in terms of a bene-

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[10] Don Fullerton (1984) provides an excellent discussion of various definitions of and differences in average and marginal returns and tax rates.

fit vs. cost calculation similar to that underlying (1). From the perspective of savers, the marginal benefit of allocating an additional dollar to saving is represented by RN_t, and the marginal cost is the decline in utility from foregone current consumption.

Return-Over-Cost Model. The second new model presented by Feldstein quantifies marginal investment incentives by contrasting the maximum potential net return, $MPNR_t$, that firms can afford on a standard investment project with the cost of funds, COF_t. In this Return-Over-Cost Model, the following decision rule equates benefits and costs and determines the desired capital stock (as in (1)),

$$MPNR_t = COF_t. \qquad (8)$$

$MPNR_t$ depends positively on a hypothetical marginal return inclusive of taxes. Dynamics enter in terms of a partial adjustment mechanism: whenever the benefits ($MPNR_t$) exceed the costs (COF_t), firms begin to acquire capital in order to reestablish (8). Assuming that net investment is positively affected by fluctuations in demand conditions, lagging the independent variables per the above discussion, and appending a stochastic error term, we obtain the Return-Over-Cost Model,

$$I_t^n/Y_t = \gamma_0 + \gamma_1\, UCAP_{t-1} + \gamma_2\,(MPNR_{t-1} - COF_{t-1}) + u_t. \qquad (9)$$

As in the Neoclassical and the Effective-Tax-Rate models, the estimated coefficients may represent both technology and expectation parameters.

Feldstein examines the degree to which net investment was affected by price variables (RN_{t-1} or $MPNR_{t-1} - COF_{t-1}$) and the quantity variable ($UCAP_{t-1}$) in the Effective-Tax-Rate and Return-Over-Cost models, as well as the effects of C_t and Y_t in his version of the Neoclassical Model. He finds generally that the price variables are able to account for most of the movement in investment since 1966. Based on the estimation and simulation of these three different specifications, he concludes that "the rising rate of inflation has, because of the structure of existing U.S. tax rules, substantially discouraged investment in the past 15 years" (p. 860).

All three of the models analyzed by Feldstein are examined critically by Chirinko (1987b). Based on a number of independent criticisms, that study concludes that none of the three models, when properly specified and evaluated, supports Feldstein's view that taxes have exerted a significantly depressing effect on business net investment between the mid 1960s and the late 1970s. For example, a modified Effective-Tax-Rate Model (with an arguably more accurate RN_{t-1}) leads to dramatic changes in the elasticity of the price (0.58 to 0.17) and quantity (0.62 to 1.76) variables. See Feldstein (1987a) for a critical discussion of Chirinko's study, and Feldstein and Joosung Jun (1987) for further results.[11]

D. *Summary and Unresolved Issues*

Our review of Implicit models has been guided by the four issues raised in Section I. Regarding empirical determinants, it appears that investment is most sensitive to quantity variables (output or sales) with price variables having only modest effects. For the Neoclassical

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[11] Using Swiss data, Georg Junge and Milad Zarinnejadan (1986) report that RN_{t-1} is statistically significant but that the impact of taxes through RN_{t-1} is quantitatively unimportant (an elasticity of 0.20). By replacing Feldstein's average tax rate with a marginal tax rate, Michael Sumner (1988) provides evidence consistent with Feldstein's original interpretation of the Effective-Tax-Rate Model. However, it is not clear how to interpret Sumner's modified RN_{t-1}, which is a curious mixture of marginal tax rates and average pretax returns.

Model, the latter conclusion may be traceable to margins used by firms but omitted in the Neoclassical framework or other specification problems.[12] J. Gregory Ballentine (1986) reports that only 8.1 percent of the dollar volume of corporate tax increases in the 1986 Tax Act (over a five year period) are reflected in the variables entering C_t. Thus, allowing taxes to enter through channels different from C_t is important for assessing the efficacy of fiscal policies, and the empirical results from the other models reviewed here further suggest a limited direct role for tax policy as historically implemented.

The other unresolved issues—model formulation, the technology specification, and expectations—have generated two contrasting responses: the introduction of *more* structure, following the pattern initiated in the Neoclassical research program, or of *less* structure, as presented in the Effective-Tax-Rate and VAR models. Which strategy is to be preferred for the study of investment behavior will be discussed in Section IV, but most research has pursued structural model-building. In response to the successes of and difficulties with the Neoclassical Model, subsequent work has been based on explicit modeling of the firm's optimization problem with careful attention to dynamics and technology, a line of research reviewed in Section III.

III. *Models with Explicit Dynamics*

> In the study of investment behavior, the most important current problem is the integration of the time structure of the investment process into the representation of technology. (Jorgenson 1971, p. 1142)

> Intertwined and largely unresolved in all of the econometric work is the critical issue of expectations . . . Major progress in discerning reliable and stable investment functions will require facing up to and illuminating the fundamental relations between past, present and future. (Eisner 1974, p. 102)

In their reviews of the state of investment theory in the early 1970s, Jorgenson and Eisner each emphasized the need for an improved understanding of the dynamics inherent in the investment process. As indicated by the above quotations, Jorgenson stressed the importance of intertemporal aspects of the technology, and Eisner highlighted difficulties with expectations. This section presents models in which these dynamic elements appear explicitly in the optimization problem and the estimated coefficients are linked explicitly to the underlying technology and expectation parameters. These include the Brainard-Tobin q, Euler Equation, and Direct Forecasting models. All of these models are based on an adjustment cost technology, and important differences will be traced to alternative treatments of dynamics arising from expectations. Differences arising from alternative descriptions of the technology will be considered in Section V.C. Paralleling Section II, the discussion is centered around a Benchmark Model, which is presented in the next subsection.

A. *The Benchmark Model*

In addressing the four unresolved issues with the Neoclassical Model, researchers have found it very useful to work with explicit models, which permit a better understanding of the dynamics

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[12] These margins might include asset churning with insufficient recapture provisions (Roger Gordon, James Hines, and Summers 1987), relations between the cost of leverage and the type of asset (Bosworth 1985), tax loss carryforwards (Auerbach and James Poterba 1987), alternative minimum taxes, or endogenous capital depreciation and utilization (Feldstein and Michael Rothschild 1974). Potential specification problems include an insufficient amount of variation in tax variables over the sample, classical measurement error (with the associated downward coefficient bias), an inappropriate discount rate for calculating z_t (Summers 1987) or, as noted in the text, biases from autonomous shocks.

due to expectations and the technology. In a number of these formal models, dynamic aspects of the technology are captured by the assumption that, in varying its capital stock, the firm faces adjustment costs. These were introduced by Eisner and Strotz (1963), and may represent either external costs, due to an upward sloping supply curve for capital goods,[13] or internal costs. Studies have generally focused on internal adjustment costs, which represent lost output from disruptions to the existing production process (as new capital goods are "broken-in" and workers retrained), additional labor for "bolting-down" new capital, or a wedge between the quantities of purchased and installed capital.[14] These costs increase at an increasing rate, an assumption that plays a crucial role in explicit models. With linear or concave adjustment costs, the firm would have an all-or-nothing investment policy. Convexity forces the firm to think seriously about the future, as too rapid accumulation of capital will prove costly. Alternatively, too little accumulation results in foregone profits.

For expositional purposes, it is useful to derive the Benchmark Model from an optimization problem. We begin by assuming that the firm chooses inputs to maximize the discounted sum of expected cash flows, which is equivalent to maximizing its market value.[15] The firm is a price-taker in both its input and output markets, and is further constrained by production, adjustment cost, and accumulation technologies. Output (Y_t) is determined by labor (L_t), capital (K_t), and a stochastic technology shock (τ_t); hence the production technology is $Y_t = F[L_t,K_t:\tau_t]$.[16] An important element in the Explicit models considered in this section is that, in contrast to variable labor input, capital is quasi-fixed—that is, net increments to the capital stock are subject to adjustment costs. These are represented by $G[I_t,K_t:\tau_t]$, which is increasing in I_t, usually decreasing in K_t, and valued by the price of foregone output. The stock of existing capital is accumulated as a weighted sum of past investments. If the weights follow a declining geometric pattern, we obtain the familiar transition equation for capital, $K_t = I_t + (1-\delta)K_{t-1}$. The price of output is the numeraire, and the relative prices of labor and investment are represented by w_t and p^I_t, respectively, adjusted for taxes. To emphasize the fundamentally forward-looking nature of the firm's decision problem, we introduce an expectations operator, $E_t\{.\}$, where the subscript indicates that expectations are based on information available to the firm at the beginning of period t. These considerations lead to the following equation for the firm's cash flow (CF_t) in period t,

$$E_t\{CF_t\} = E_t\{F[L_t,K_t:\tau_t] - G[I_t,K_t:\tau_t] - w_tL_t - p^I_tI_t\}. \quad (10)$$

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[13] External adjustment costs are very much in the spirit of Keynes' short-run analysis: "If there is an increased investment in any given type of capital during any period of time, the marginal efficiency of that type of capital will diminish . . . partly because, as a rule, pressure on the facilities for producing that type of capital will cause its supply price to increase . . . [this factor is] usually more important in producing equilibrium in the short run" (Keynes 1936, p. 136). See Michael Mussa (1977) and fn. 33 for further discussion of external and internal adjustment costs.

[14] These different rationales determine whether the price of output, labor, or new capital is appropriate for valuing adjustment costs. See Louis Maccini (1987) for a recent review of the adjustment cost literature.

[15] It is important to note that, with this maximand, the firm is uninterested in the higher moments of the stream of cash flows and its correlation with the owners' consumption path. Furthermore, potential conflicts among shareholders, bondholders, and managers are ignored.

[16] With no loss in analytic insights but much saving in notation, we assume that production is affected by the end-of-period capital stock and, below, that the discount rate is constant.

With the restriction implied by the capital accumulation constraint, the firm has two margins along which to maximize the sum of expected cash flows discounted to the beginning of the planning period (t) at rate r, and faces the following optimization problem,

$$\underset{\{L_s,K_s\}}{\mathrm{MAX}}\, E_t \left\{ \sum_{s=t}^{\infty} \{(1+r)^{-(s-t)}\{F[L_s,K_s:\tau_s] - G[I_s,K_s:\tau_s] - w_s L_s - p_s^I I_s\}\} \right\} \quad (11a)$$

$$\text{subject to} \quad I_s \equiv K_s - (1-\delta)K_{s-1}. \quad (11b)$$

Using variational methods and differentiating (11) with respect to labor and capital, we obtain the following conditions characterizing an optimum,[17]

$$E_t\{F_L[L_t,K_t:\tau_t] - w_t\} = 0, \quad (12a)$$

$$E_t\{\lambda_t - \Delta^\rho\{G_I[I_t,K_t:\tau_t]\} - \Delta^\rho\{p_t^I\} = 0, \quad (12b)$$

$$\begin{aligned} \lambda_t &\equiv F_K[L_t,K_t:\tau_t] - G_K[I_t,K_t:\tau_t], \\ \Delta^\rho\{X_t\} &\equiv X_t - \rho\, X_{t+1},\ X_t = \{G_I[t],p_t^I\} \\ \rho &\equiv (1-\delta)/(1+r) < 1, \end{aligned}$$

$$\lim_{s\to\infty} E_t\{(1+r)^{-(s-t)}\{\lambda_{t+s} - p_{t+s}^I - G_I[t+s]\}K_{t+s}\} = 0. \quad (12c)$$

These conditions have the following economic interpretations. Equation (12a) is the familiar marginal productivity condition for a variable input (L_t). Equation (12b) indicates that, along the optimal capital accumulation path, the firm will be indifferent to an increase in capital by one unit in period t and a decrease of $(1-\delta)$ units in $t+1$, thus leaving the capital stock unaffected from period $t+1$ onward. The benefit of this perturbation is represented by λ_t—the marginal revenue product of capital net of the decrease in adjustment costs due to a higher level of capital. Perturbing the capital stock is costly, and the Euler Equation (12b) sets λ_t equal to the marginal adjustment and purchase costs incurred in t and saved in $t+1$. These perturbations are represented by the $\Delta^\rho\{\cdot\}$ operator in (12b), and the $t+1$ savings are adjusted for discounting and depreciation as represented by ρ.

The transversality condition is provided by (12c), and restricts the value of the firm and the value of the capital stock from exploding. Its importance in applied work arises as a boundary condition used in obtaining the following solution to the difference equation (12b) for capital,[18]

$$E_t\{\Lambda_t - p_t^I - G_I[I_t,K_t:\tau_t]\} = 0, \quad (12d)$$

$$\Lambda_t \equiv \sum_{s=0}^{\infty} \rho^s \lambda_{t+s}. \quad (12e)$$

Equation (12d) is the dynamic equivalent of the simple decision rule for the optimal capital stock (1) in Section II, and equates the expected marginal benefits and costs of investing in period t. The marginal benefit is measured by the shadow price of capital, Λ_t. Owing to capital's durability, this is the discounted sum of the "spot" marginal revenue products (λ_{t+s}'s) over the life of the capital good as evaluated with information available in period t. The marginal costs are the sum of purchase costs and the sunk adjustment costs associated with investing. Because the sunk costs cannot be recovered, they force the firm to look ahead when

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[17] See Thomas Sargent (1987, chs. IX and XIV) for further discussion of dynamic optimization problems. We assume throughout that the firm's optimal investment policy always results in $I_t > 0$, a very reasonable assumption at the aggregate and industry level.

[18] An alternative and more direct method for obtaining (12d)—but at the expense of highlighting the role of (12b) and (12c)—is to analyze the optimization problem as a Lagrangian, append the capital accumulation constraint with λ_t as a multiplier, transform the constraint to obtain Λ_t, and differentiate with respect to I_t (Chirinko 1991).

investing.[19] Thus, the optimal investment policy can be characterized by two alternative formulations—comparison of the net benefits of investing today versus tomorrow (12b) or a comparison of the benefits over the life of the capital good to its costs (12d).[20]

To obtain an investment equation to serve as a benchmark for the models found in the literature, we assume that adjustment costs are quadratic in gross investment, homogeneous of degree one in I_t and K_t, and affected by the technology shock, τ_t,

$$G[I_t,K_t{:}\tau_t] = (\alpha/2)\,[I_t/K_t - \tau_t]^2 * K_t, \qquad (13)$$

and obtain the following Benchmark Model,

$$I_t/\mathrm{K}_t = (1/\alpha)\,(E_t\{\Lambda_t\} - p^I_t) + u_t, \qquad (14)$$

where the error term is identical with the technology shock.[21] Whenever there is a discrepancy between $E_t\{\Lambda_t\}$ and p^I_t, the firm has an incentive to change its capital stock, but its actions are tempered by the convex adjustment cost technology. The steeper is the adjustment cost function, the larger is α, and the more slowly investment responds. In contrast to the Implicit models, the path of investment does not depend on the optimal capital stock, and lag variables do not appear in (14). The latter is somewhat surprising given the dynamic adjustment costs faced by the firm. It must be realized, however, that (14) is not a closed-form decision rule for investment (because I_t affects the λ_{t+s}'s in Λ_t), but rather a consistency condition reflecting only part of the information from the optimization problem. If the other restrictions implied by optimal behavior were considered simultaneously, then the paths of I_t and K_t would be "sluggish," and would depend on lagged variables.[22]

The Benchmark Model is the basis for all of the models discussed in this section,[23] and successfully addresses a number of the unresolved issues highlighted in the Neoclassical research program. Because (14) is derived directly from an optimization problem, it is theoretically consistent, recognizes explicitly the dynamics due to expectations and technology, and isolates their separate influences. Furthermore, the error term follows explicitly from the theory. For empirical researchers, the critical problem with developing an estimable equation from (14) is relating the unobservable Λ_t to observable variables. As we shall see, extant investment models based explicitly on adjustment costs dif-

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[19] In a more general model, purchase costs could be partially sunk insofar as capital assets are designed for specific uses or the used market for capital goods is plagued by adverse selection problems. In addition, future training and maintenance costs, which may be necessarily for a period t investment to function in period $t + s$, could be represented by a discounted sum, similar to Λ_t, replacing p_t^I.

[20] A similar distinction exists in the consumption literature between the Euler Equation and Permanent Income/Life Cycle models.

[21] Equation (14) would contain a constant if adjustment costs were quadratic in net investment or if (13) contained a term linear in I_t/K_t. Apart from τ_t, additional sources of error could arise from expectations (e.g., if p_t^I is dated after the beginning of period t), mismeasurement, differential information sets available to the firm and the econometrician, optimization error, and serial dependence in the technology shock.

[22] Under static expectations and an approximation about the steady-state capital stock, this adjustment cost model would also generate lags in an econometric equation. With these assumptions, we obtain the partial (or stock) adjustment model with I_t proportional to the spread between the actual and desired capital stocks (Eisner and Strotz 1963; Brechling 1975, ch. V). However, the relation between technology parameters and the estimated coefficients is blurred by the approximation and by the dependence of the constant of proportionality on the interest rate. Coupled with the assumption of static expectations, this approach is too restrictive for the study of investment.

[23] Additionally, the user cost of capital (2) can be derived from (12b) or (12d) when adjustment costs are absent, expectations are static, and the optimization problem is stated in continuous time (Jorgenson 1967, pp. 140–44).

fer only in how researchers solve this problem.

B. *q Models*

Theory. The q theory of investment—introduced by Keynes (1936) and revitalized and elaborated by William Brainard and James Tobin (1968) and Tobin (1969, 1978)—uses information in financial markets to relate $E_t\{\Lambda_t\}$ to observables. In this theory, investment expenditures are positively related to Average q, defined as the ratio of the financial value of the firm (V_t) to the replacement cost of its existing capital stock,

$$q_t^A = V_t / p_t^I K_t. \qquad (15)$$

The intuition underlying q theory has been articulated vividly by Keynes (1936, p. 151),

> daily revaluations of the Stock Exchange,. . ., inevitably exert a decisive influence on the rate of current investment. For there is no sense in building up a new enterprise at a cost greater than that at which a similar existing enterprise can be purchased; whilst there is an inducement to spend on a new project what may seem an extravagant sum, if it can be floated off on the Stock Exchange at an immediate profit.

The relation between these intuitive notions and formal models has been developed in a series of papers. Andrew Abel (1980), Lucas and Edward Prescott (1971), and Mussa (1977) demonstrate that the adjustment cost technology and optimizing behavior lead to a relation between investment and Marginal q, the ratio of the discounted future revenues from an additional unit of capital to its purchase price (i.e., $E_t\{\Lambda_t\}/p_t^I$). Because Marginal q is unobservable, empirical researchers have utilized observable Average q.[24] The formal conditions under which this substitution is appropriate have been established by Fumio Hayashi (1982, 1985): 1) product and factor markets are competitive, 2) production and adjustment cost technologies are linear homogeneous, 3) capital is homogeneous, and 4) investment decisions are largely separate from other real and financial decisions. Under these conditions, optimizing behavior implies the following relation for the value of the firm as evaluated on financial markets,[25]

$$V_t = E_t\{\Lambda_t\}\, K_t, \qquad (16)$$

where V_t is in constant dollars. To understand (16), note that the assumptions on market structure and technology ensure that the firm does not expect to earn any profits from actions taken in and beyond period t. Hence, the value of the firm equals the quasi-rents from the existing capital stock, which are the product of the expected shadow price of capital and K_t.[26]

The q investment model follows from (14)–(16),

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[24] The "Brainard-Tobin q" should be distinguished from "Jorgenson's q." In the Jorgenson (1963) framework, q is defined as both the purchase price of investment and the discounted stream of future marginal revenue products, which are equal in his model without adjustment costs. In the Brainard-Tobin framework, the difference between these two prices is the central element in the investment model, and is represented by a departure of q from unity.

[25] Additional restrictions underlying (16) are that delivery, expenditure, and gestation lags are nonexistent or highly restrictive and that capital depreciates geometrically. Depending on timing assumptions, the right side of (16) might be multiplied by $(1 - \delta)$—reflecting that existing capital depreciates immediately while new capital begins depreciating next period—or divided by $(1 + r)$—reflecting that returns become available at the end of the period while V_t is dated at the beginning of the period.

[26] Tax depreciation allowances accruing after period t on capital purchased prior to period t (i.e., a depreciation "bond") will enter as an additional positive term on the right side of (16). See Hayashi (1982, equations (5) and (14)). Interest and principal payments on debt existing prior to but paid after period t enter in a similar manner, though on the left side of (16). In applied work, net current financial assets, inventory stocks, and other capital assets are added to the right side of (16). Goodwill and firm-specific human capital should also be included, but are difficult to quantify.

$$I_t/K_t = (1/\alpha)\, q_t + u_t,$$
$$q_t \equiv (q_t^A - 1)\, p_t^I, \qquad (17)$$

where the latter term in q_t depends on the valuation of adjustment costs.[27] Equation (17) solves the problem of unobservable expectations by equating a forward-looking variable to one that is readily observed. Given q_t, we have a great deal of information about future conditions affecting investment without having to make specific assumptions about expectations formation or future conditions of supply and demand. For a forward-looking firm constrained by adjustment costs, I_t/K_t should be solely determined by contemporaneous q_t. If p_t^I is known at the beginning of the period and u_t is due only to contemporaneous technology shocks then, because q_t is dated at the beginning of the period, ordinary least squares generates consistent estimates of α.[28]

Equation (17) (and many variants thereof) has been the most popular Explicit model in empirical investment studies. A particularly attractive aspect is that, unlike the Neoclassical or other Implicit models (cf. (6), (7), and (9)), the q investment equation will not be affected by instability in expectations parameters because expectations enter (17) directly through q_t^A. By relying on financial market data, which in principle incorporates expectations of future variables relevant to the investment decision (and are readily available), q models provide a direct role for expectations in the econometric specification. Furthermore, like all Explicit investment equations, q models resolve a number of issues from the Neoclassical research program. Despite these benefits, the usefulness of q theory is called into question by its generally disappointing empirical performance, a point that will be explored in depth in the next two subsections.

Key Assumptions and Caveats. There are two major caveats pertaining to the q model. The first involves possible mismeasurement of the three components of Average q (15), and each is reviewed below. (Unless otherwise noted, empirical results are based on data for the United States.) The most pressing measurement issue concerns the variability in q_t^A stemming from V_t. Recent studies have questioned the reliability of financial asset prices in evaluating the underlying cash flows (see the survey by LeRoy, 1989). Differentials between market values and fundamentals are generally attributed to "investor sentiment," that is, excess volatility, mean reversion, fads, or speculative bubbles in financial markets. Sentiment creates a problem for the q model insofar as investment decisions are based on fundamentals.[29]

The role of investor sentiment relative to fundamentals has been examined with investment models in three ways. First,

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[27] If adjustment costs are valued in terms of labor or new capital (cf. fn. 14), then p_t^I (the purchase price of new capital relative to the price of output) in (17), is replaced by p_t^I/w_t or 1.0, respectively.

[28] The validity of maintaining that q_t is predetermined has been questioned by Hayashi and Tohru Inoue (1991), who argue that q_t will be correlated with u_t. However, this correlation depends critically on their particular timing assumption and, in more general circumstances, the Hayashi-Inoue critique does not hold (Chirinko 1993). If u_t is serially correlated, consistency can be preserved by quasi-differencing (17), thus justifying lagged variables in the q model.

[29] The extent to which firms should react to investor sentiment is debatable. Bosworth (1975) views the stock market as a "sideshow," and claims that it should be ignored in investment decisions. Stanley Fischer and Robert Merton (1984) argue that, as the market is a source of finance, firms should exploit investor sentiment, undertaking investment when buoyant markets lower financing costs. Olivier Blanchard, Changyong Rhee, and Summers (1993) contend that the proper response is ambiguous and depends on whether managers are representing existing or new shareholders, whether the proceeds from a new issue are invested in financial assets or physical capital, and the nature of information problems in equity markets.

band spectrum regression has been used to separate the noise from that part of q_t^A presumably containing an accurate signal of the firm's fortunes. Robert Engle and Duncan Foley (1975) assume that the signal would be in the middle frequencies with a period of two years, and enjoy some econometric success with their adjusted asset price series (whose variance is only 13% of that of the original series). Second, instrumental variables may correct this measurement error problem that, by a standard errors-in-variables analysis, would bias α upwards, but this technique has not generally had appreciable effects on empirical results based on (17).[30] Third, Blanchard, Rhee, and Summers (1993) investigate the behavior of the residuals from the q model circa Black Thursday in 1929 and Black Monday in 1987, but no consistent patterns emerge. They further decompose q_t^A into a market valuation term and a fundamental profit term, but their empirical results do not permit them to draw strong conclusions about the relative importance of these two components. This finding, coupled with the evidence from other studies, is insufficient to determine whether investor sentiment undermines the q model.

An additional measurement problem concerns a possible systematic bias stemming from a mismeasured capital stock in the denominator of q_t^A. This stock is calculated by a perpetual inventory method with a fixed set of straight-line depreciation rates that may have become highly inaccurate in the face of major structural shifts. The rapid rise in energy prices in the 1970s and the revolution in office computing machinery in the 1980s may have made part of the existing capital stock obsolete, forcing firms to accelerate depreciation and retirements. Some of these machines may have been modified in response to changing relative prices, but the net impact is that published capital stock series with fixed depreciation rates will overstate the replacement value of the existing capital stock. The extant evidence provides little support for the capital mismeasurement hypothesis.

Finally, the tax and nontax components of p_t^I are a third possible source of measurement problems, and each is reviewed in Chirinko (forthcoming a). As the greatest variability in q_t^A comes from its numerator, it is doubtful that mismeasurement of these terms (or K_t) is of first-order importance.

The second major caveat with (17) concerns the conditions (listed above (16)) permitting q_t to proxy for $E_t\{\Lambda_t\}$. The extent to which these conditions can be relaxed within the q framework has been investigated by researchers motivated by the empirical difficulties with the q model (discussed in the next subsection).

Imperfect competition in the product market disrupts the relation between the financial value of the firm and the shadow price of capital in (16), and results in the marginal return to capital being less than the average return. This discrepancy can be captured by an infinite forward sum of future outputs weighted by the rates of discount and depreciation and multiplied by a parameter, θ, representing the negative inverse price elasticity of demand (Hayashi 1982). Chirinko and Fazzari (1988) extend this result to incorporate both nonconstant returns and imperfect competition (which are likely to occur jointly). To obtain an econometric q model, they remove most of the terms in the infinite sum by quasi-for-

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[30] Measurement error can be assessed by comparing first and longer differences of (17) estimated with panel data, and does not appear to be quantitatively important (Takeo Hoshi and Kashyap 1990). Alternatively, econometric problems associated with a mismeasured q can be attenuated by normalizing (17) by q; there is mixed evidence that q is measured with error (Chirinko and Huntley Schaller 1991; Chirinko 1993).

ward-differencing the model with a Koyck (lead) transformation,[31]

$$\Delta^r\{I_t/K_t\} = (1/\alpha)\,\Delta^r\{q_t\} + ((\eta - \theta - \eta\theta)/\alpha)\,(Y_t/K_t) + u_t, \quad (18)$$

where $(1 + \eta)$ is the degree of homogeneity of the production function and $\Delta^r\{\cdot\}$ is the quasi-forward difference operator similar to (12b) with ρ replaced by $(1 + r)^{-1}$.[32] Loosely speaking, (18) is a "reverse accelerator"; conditioned on $\Delta^r\{q_t\}$, the *change* in investment is related to the *level* of output (cf. (5) with $\sigma = 0$). Furthermore, (18) indicates that the frequent practice of justifying a positive output (or sales) term in a q model with the assumption of nonconstant returns or noncompetitive markets is inappropriate; in the latter case, output enters with a negative sign.[33] Estimates of (18) with firm level panel data for 12 U.S. industries by Chirinko and Fazzari (1988) and with aggregate data and $\eta = 0$ for the United Kingdom by Schiantarelli and Georgoutos (1990) reveal an improved empirical performance, but important problems remain.

The assumption of homogeneous capital is also a key element in the q model, and has been relaxed in three ways. First, the value of the firm is allowed to depend on two or more capital goods having different adjustment cost technologies (Chirinko 1982, 1993; David Wildasin 1984). Second, rather than being an arithmetic sum of several capital components, the investment and capital aggregates in (17) are constructed using the standard theory of index numbers and the user cost for each type of capital as weights (Hayashi and Inoue 1991). Third, the importance of the putty-putty capital assumption is examined by comparing (17) to a putty-clay q equation in which ex post substitution between capital and variable factors is strictly precluded. Although the overall performance of the q equation improves under these extensions, the estimates are still unsatisfactory.

Finally, interactions among investment and other real and financial decisions may invalidate the simple q model. For example, when financial policy is endogenous, q_t is likely to be an uninformative, and possibly misleading, signal for investment expenditures (Hayashi 1985; Chirinko 1987a). When (17) is modified to allow for endogenous financial policy in the latter study, the empirical performance of the q model improves little.

Thus, neither mismeasured components of q_t nor the restrictiveness of the conditions permitting q_t to proxy for $E_t\{\Lambda_t\}$ appear to be responsible for the shortcomings discussed in the next subsection.

Empirical Results. The q model's empirical performance has been generally unsatisfactory, and will be reviewed in terms of the statistical significance of q_t and the fit of the equation. One of the earliest analyses using the financial value of the firm is presented by Yehuda Grunfeld (1960), who finds that his approximate q variable "explains a larger proportion of investment behavior than either lagged or current profits" (p. 233). Most studies do not estimate the q equation

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[31] Fabio Schiantarelli and D. Georgoutos (1990) also propose the use of the Koyck transformation, but on the Hayashi model. Note that θ can vary over time but that η must be parametric and ρ nonstochastic.

[32] Note that u_t is likely to be correlated with the regressors and is more complicated than the error term in the standard q model. In (18), u_t contains shocks to the adjustment cost technology (entering as MA(1)), shocks to the production technology, and expectation errors from variables unknown at time t.

[33] If factor markets are noncompetitive, then there is an additional infinite forward sum of nominal investments multiplied by the (negative inverse) supply elasticity that reflects the difference between marginal and average valuations of capital. External adjustment costs can be interpreted in terms of this supply elasticity, and thus lead to a much different specification than (17), which is based on internal adjustment costs.

as specified by (17), but rather introduce on an ad hoc basis current and lagged quantity variables, as well as lags of investment and q_t. In models with distributed lags of q_t, John Ciccolo (1975) and Engle and Foley (1975, with a capacity utilization variable) show q_t to play a significant role.

These initially encouraging results with aggregate data have not been sustained in more recent work. In equations with capacity utilization, capital stock, and taxes, von Furstenberg (1977) concludes that including a distributed lag of q_t in quarterly regressions "must be regarded as optional" (p. 388). Studies by Summers (1981), Blanchard and Charles Wyplosz (1981), and Hayashi (1982) generate rather low R^2's and substantial residual serial correlation. In his comparison of various investment theories, Peter Clark (1979) shows that a distributed lag q model does not perform adequately in terms of either within sample or out-of-sample statistics. A somewhat similar mix of results has been forthcoming with disaggregate data. The results discussed so far are based on U.S. data, and a broadly similar pattern has been reported with data from other countries.

Apart from the statistical significance of q_t and goodness of fit, a complementary approach for evaluating the q model is to compare its theoretical implications to the empirical results. In terms of (17), there have been three persistent discrepancies discussed in the literature. First, the dynamics appear to be inadequate: specification tests indicate the presence of serially correlated residuals and lagged (I_t/K_t) and q_t are usually very significant. The importance of these lags is frequently justified by the assumption of delivery lags, multi-period adjustment costs, or other dynamic elements in the technology. However, these ex post rationalizations are wholly inappropriate in the context of Explicit models, which require that all assumptions enter prior to the characterization of the optimal investment policy. When incorporated into the optimization problem, the resulting specifications bear little resemblance to the estimated equations.[34]

Second, (17) implies that, conditioned on q_t, no other variables should have a systematic relation to investment, but quantity variables—such as liquidity and output—are frequently statistically significant. The role of liquidity in q models will be discussed in Section V.A. As indicated by (18), output can enter a q model but, pending structural interpretations of estimated coefficients, our understanding of the role of quantity variables remains incomplete.

However, the validity of these two criticisms depends on the properties of the error term and the estimation technique. If u_t contains a technology shock correlated with endogenous liquidity and output, then these terms would be expected to be significant in models estimated by ordinary least squares. This significance should disappear when the parameters are estimated with instrumental variables orthogonal to the error. Furthermore, significant lagged variables (with the appropriate parametric restrictions) are consistent with a serially correlated technology shock.

The third and perhaps the most important criticism of the q model is that estimated adjustment costs are unreasonably large. For example, when constrained by a geometric lag distribution, the results of Ciccolo (1975) imply that the mean lag of the adjustment to a change in the long-run capital stock is seven years (Hall 1977, p. 89). With an α of 32.0, Summers (1981, p. 101) reports that, twenty years after an unexpected change in the economic environment, the capital stock

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[34] Studies that purportedly resolve this problem usually do not fully recognize important differences between Marginal and Average q.

would have moved only three-fourths of the way to its ultimate steady-state value. Most studies, especially with panel data, generate much larger α's.

Given the direct treatment of expectations, the poor empirical performance of q models is disappointing, and does not appear to be traceable to some of the "usual suspects" discussed previously. We conclude this review of empirical work with a consideration of the effects of tax policy. In contrast to the Implicit models, most q studies have been primarily concerned with estimation and, with the exception of Summers (1981), have not assessed the effects of alternative policies. In Implicit models, the change in investment spending due to changes in tax parameters is a straightforward computation. In q models, however, the analysis is more complicated, and is conducted in two stages: relating changes in tax parameters to changes in q_t, which, in turn, affect investment through the estimated parameters in the econometric equation. The first stage is particularly involved because we have to quantify the response of asset prices to an alternative sequence of tax parameters that will affect current and future investment, which will feedback into q_t. This task is accomplished by solving for investment, the capital stock, and q_t simultaneously over an approximately infinite horizon.

Summers' calculations suggest that taxes, raised by the interaction of inflation with a nonneutral tax code, can have significant effects on capital accumulation. However, this result follows from the large tax increases generated from his specification of the tax code. With the per dollar of tax loss serving as a basis for comparison, the cumulative change in the capital stock after five years and with $\alpha = 32.0$ ranges between \$0.18 and \$0.37 in Summers' model. This estimated adjustment cost parameter is comparatively small, and larger α's would lead to even less response of the capital stock both along the transition path and in the ultimate steady-state. Thus, in concert with the thrust of the empirical results from Implicit models, the response of investment spending to tax policy is quite small in q models.

C. *Euler Equation Models*

Theory. As mentioned at the beginning of Section III, Explicit investment models differ only by the way in which they solve the problem of unobservable expectations. In the Benchmark Model, the unobservables are represented by $E_t\{\Lambda_t\}$, the shadow price of capital defined as the discounted sum of the "spot" marginal revenue products (λ_{t+s}'s) over the life of the capital good. The model considered in this subsection solves the unobservable expectation problem in one of two equivalent ways. In the Benchmark Model, the bulk of the variables in $E_t\{\Lambda_t\}$ can be eliminated by a Koyck-lead transformation (Abel 1980).[35] An alternative and more direct approach combines the Euler Equation (12b) and the adjustment cost technology (13). In either case, we obtain the following equation,

$$\begin{aligned} I_t/K_t = \rho E_t\{I_{t+1}/K_{t+1}\} \\ - (1/\alpha)(p_t^I - \rho\, E_t\{p_{t+1}^I\}) \\ + (1/\alpha)E_t\{\lambda_t\} + \tau_t. \quad (19) \end{aligned}$$

The importance of (19) is that the infinite number of unknown λ_{t+s}'s ($s = 0,\infty$) has been reduced dramatically to just λ_t.

Estimation proceeds by parameterizing λ_t in terms of the technology (cf. (12b)) and substituting actual for expected values in (19). Under rational ex-

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[35] To obtain (19) from the Benchmark Model, state (14) in period $t + 1$, take expectations based on information available in period t using the law of iterated expectations (i.e., $E_t\{E_{t+1}\{\Lambda_{t+1}\}\} = E_t\{\Lambda_{t+1}\}$; see Sargent 1987, ch. X), multiply by ρ and, noting that $E_t\{\Lambda_t\} = E_t\{\lambda_t\} + \rho\, E_t\{\Lambda_{t+1}\}$, subtract from (14).

pectations, the actual values represent the appropriate expectation up to an additive and orthogonal expectation error (Bennett McCallum 1979), and thus (19) yields the following Euler Equation Model,[36]

$$I_t/K_t = \rho\, I_{t+1}/K_{t+1} - (1/\alpha)\,(p^I_t - \rho\, p^I_{t+1}) + (1/\alpha)\,\lambda_t + u_t, \qquad (20)$$

$$u_t = \tau_t + \epsilon_t - \rho\, \epsilon_{t+1},$$

where the error term is a combination of technology shocks and expectation errors (ϵ's). Because u_t is correlated with the regressors, instrumental variables are needed to ensure consistency. The projection of an endogenous variable dated $t + 1$ on the instruments can be interpreted as a one-period ahead forecasting equation assumed stable over the sample period.

Key Assumptions and Caveats. The only important caveat with the Euler Equation Model is that it is based on a limited amount of information from the firm's optimization problem. This limitation may prove beneficial if the information contained in the other equations is suspect or more sensitive to certain types of misspecification. As we shall see here and in Section V.B, there is no necessary reason for restricting estimation to just this one characteristic of optimal firm behavior.

An additional criticism is that the Euler Equation Model does not solve fully the unobservable expectations problem because the presence of λ_t and the $t + 1$ variables in (20) requires that the parameters are estimated by instrumental variables. Peter Garber and Robert King (1983) have argued that technology shocks will lead to identification problems in (20) and that serially correlated technology shocks will invalidate most candidate instrumental variables.[37] This is not a problem with the Euler Equation approach per se, but rather a useful reminder of the general difficulty of finding appropriate instruments, an issue discussed with respect to VAR models in Section II.C.

Empirical Results. Price and output elasticities have varied widely with Euler Equation models, all of which have been based on data for U.S. manufacturing. Using quarterly data, Abel (1980) obtains elasticities of I_t/K_t with respect to Λ_t/p^I_t (holding Λ_t constant) ranging from 0.58 to 1.11 and elasticities of substitution between labor and capital between 0.25 and 0.50. The remaining studies reviewed here analyze the Euler Equation Model in conjunction with other constraints from the optimization problem; with one exception, all use annual data. Robert Pindyck and Julio Rotemberg (1983a) estimate simultaneously the Euler Equations for quasi-fixed labor and capital, cost share equations for variable energy and materials, and the cost function. For a cost-minimizing firm, they find capital to be highly responsive in the long run both to its own price (elasticity of −2.93) and output (1.48). In a subsequent study also based on a translog specification, Pindyck and Rotemberg (1983b) obtain significantly lower elasticities of −0.13 and 0.73, respectively.[38] A similar pattern of elasticities is obtained by Cather-

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[36] Note that a number of studies with the Euler Equation Model replace the (I_t/K_t)'s in (20) with K_t's using (11b) and a different adjustment cost technology. Furthermore, in the context of this survey, labeling (20) as the "Euler Equation Model" is a bit misleading. As (12b) enters the Benchmark Model (14), all Explicit models are, in a sense, Euler Equation models. To avoid the misleading terminology and in the spirit of the derivation, (20) could be referred to as the "Transformation Model."

[37] This concern receives some support from the rejection of the orthogonality conditions between instruments and residuals in some, but not all, Euler Equation studies.

[38] The disparity between the two studies may stem from additional data over a volatile period (1972–1976), the absence of energy and materials inputs, the inclusion of debt finance, or the disaggregation of labor in the latter study.

ine Morrison (1986) for a cost-minimizing firm with static expectations; long-run price and output elasticities are −0.18 and 0.71, respectively. Under forward-looking expectations, she finds that the comparable elasticities fall to −0.05 and 0.52, respectively. Somewhat greater responsiveness for a cost-minimizing firm is reported by Jeffrey Bernstein and Nadiri (1989), who analyze four two-digit SIC industries and obtain long-run price and output elasticities that cluster closely around −0.45 and 1.06, respectively. In a model with endogenous capital utilization, profit-maximization, and quarterly data, Matthew Shapiro (1986b) calculates that the long-run price elasticity of the capital stock is only −0.31 but the comparable elasticity for the workweek of capital is −0.97.[39] This large elasticity for the flow of capital services should be interpreted with some caution because a Cobb-Douglas production technology is maintained and, given the construction of the capital utilization measure, the workweek of capital may be proxying for output.

It is difficult to evaluate the performance of the Euler Equation per se because the above results reflect cross-equation parameter restrictions. With panel data, Euler Equations have been estimated in isolation to study the effects of liquidity constraints (cf. Section V.A), and these results are encouraging, though the instruments and residuals tend to be correlated in these overidentified models.[40] Nonetheless, the generally reasonable estimates there and reported above suggest that the Euler Equation Model, perhaps in combination with other information from the optimization problem, performs reasonably well.

D. *Direct Forecasting Models*

Theory. This class of models solves the problem of unobservable expectations by forecasting directly the unknown λ_{t+s} terms in Λ_t. A key element in this solution is the assumed stochastic processes governing λ_t, which, for expositional convenience, can be specified as a first-order univariate autoregression,

$$\lambda_t = \mu\,\lambda_{t-1} + \epsilon_t, \qquad (21)$$

where μ is an expectation parameter and ϵ_t is an expectation error. Under rational expectations, ϵ_t is orthogonal to all variables known to the firm in period t. Combining this assumption with (21), we compute the expected value of λ_{t+s} with information available in period t with the following simple recursive relation,

$$E_t\{\lambda_{t+s}\} = \mu^{s+1}\,\lambda_{t-1}. \qquad (22)$$

Note that the variable(s) in the period t information set can be interpreted as an instrument.

The Direct Forecasting approach has been implemented by estimating the equations describing forecasts and optimization either simultaneously or sequentially. In the former case, (22) is substituted repeatedly into the Benchmark Model (14), thus replacing the unobserved $E_t\{\Lambda_t\}$ as follows,

$$\begin{aligned} E_t\{\Lambda_t\} &= \sum_{s=0}^{\infty} \rho^s\,E_t\{\lambda_{t+s}\} \\ &= \lambda_{t-1} \sum_{s=0}^{\infty} \rho^s\,\mu^{s+1} \\ &= \lambda_{t-1}\,(\mu/(1-\rho\mu)), \qquad (23) \end{aligned}$$

and generating the Closed-Form Model,

$$\begin{aligned} I_t/K_t = {} & (\mu/\alpha(1-\rho\mu))\,\lambda_{t-1} \\ & - (1/\alpha)\,p_t^I + u_t, \qquad (24) \end{aligned}$$

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[39] Shapiro (1986a, 1986b) overcomes the Garber-King Critique by specifying the production function as $Y_t = F[L_t,K_t{:}\tau_t] = f[L_t,K_t]\exp[\tau_t]$ and imposing this constraint on the estimating equations, thus allowing output to appear in the Euler Equation.

[40] In aggregate data, the Euler Equation tends to generate negative values of α, though this result appears to be sensitive to the inclusion of a linear term in the adjustment cost technology.

where u_t contains only τ_t and is orthogonal to λ_{t-1}.[41] As with a number of the Implicit models, the estimated coefficients in (23) are an amalgam of the underlying expectation (μ) and technology (α) parameters and the discount rate (ρ). These are identified by estimating the stochastic forcing process (21) and the investment decision rule (24) simultaneously.[42]

Alternatively, the Two-Step Model separates the forecasting of expected values from the estimation of technology parameters. In the first step, $E_t\{\Lambda_t\}$ is quantified in terms of parameters and variables known at time t by estimating the expectation parameter in (21) and then computing the $E_t\{\lambda_{t+s}\}$'s with (22) and $E_t\{\Lambda_t\}$ with (12e) and a preset ρ. In the second step, the constructed $E_t\{\Lambda_t\}$ is inserted as a regressor in the Benchmark Model (14), and α is estimated.

Key Assumptions and Caveats. There are four caveats that affect the Closed-Form and Two-Step Forecasting models to differing degrees. First, being defined in terms of L_{t+s} and K_{t+s}, λ_{t+s} is endogenous, but (21) fails to reflect the intertemporal relations between today's investment and tomorrow's marginal revenue products. This difficulty can be overcome by relating λ_{t+s} to some exogenous process and approximating the technology linearly. To form such a link, we assume that adjustment costs are independent of the capital stock ($G_K[.] = 0$), the production technology is linear homogeneous, and w_t is exogenous to the firm and evolves according to a process similar to (21). In this case, the marginal products for labor and capital can be stated in terms of the labor/capital ratio and, with (12a), $\lambda_t = f[L_t/K_t] = g[w_t] = \psi w_t$, where the latter expression represents a linear approximation (Gould 1968).[43] For Closed-Form and Two-Step models, the λ_t's in (21) and (24) are replaced by w_t's.[44] We thus obtain an investment function that is truly Neoclassical, depending solely on relative factor prices (though output could appear for a cost-minimizing firm subject to an exogenous output constraint).

A second caveat with Direct Forecasting models concerns the representation of the expectations formation process by (21). As noted for the Implicit models, these forecasting equations will be useful only insofar as the relations between past and expected future variables remain stable. Furthermore, will the forecasts of $E_t\{\Lambda_t\}$ differ appreciably from $E_{t+1}\{\Lambda_{t+1}\}$? Because these forecasts are based on a set of exogenous variables that may be highly serially correlated, it is probable that, for empirically plausible processes, forecasts will be similar, and hence unable to capture cyclical move-

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[41] A more customary procedure for obtaining a closed-form decision rule for I_t (or K_t) is to assume initially that the production and adjustment cost technologies are linear-quadratic and then solve for the closed-form decision rule from the resulting linear Euler Equation, which has the certainty equivalence property of separating forecasting and optimization (Sargent 1987, ch. XIV).

[42] Additional lags in (21) will result in an overidentified system with testable cross-equation restrictions. Parameters can be estimated by maximum likelihood (Lars Hansen and Sargent 1980) or instrumental variables (Hansen and Sargent 1982), and additional restrictions from the product demand schedule or industry equilibrium can be imposed (Lucas and Prescott 1971; Sargent 1987, ch. XIV).

[43] If the technology shocks are serially correlated, then τ_t must be separable from the other arguments in the production function, thus allowing the future marginal products to be independent of τ_t.

[44] The Two-Step Model allows a somewhat more flexible specification of the technology. For example, assume that g[.] is defined with respect to some technology parameters (σ from a CES production function) and evolves according to a stochastic process similar to (21). Then $\lambda_t = g[w_t:\sigma]$ and the other parameters can be estimated iteratively: define λ_t in terms of w_t and a preset value of σ, compute (21) and $E_t\{\Lambda_t\}$ with the conditional λ_{t+s}'s, estimate (14) with the conditional $E_t\{\Lambda_t\}$, and select the "best" parameter vector by some statistical criterion.

ments in investment spending.[45] This problem may be acute for the Closed-Form Model because the parametric restrictions between (21) and (24) can be imposed only with relatively simple expectations schemes.

A third difficulty is that some Direct Forecasting models are based on an approximation about a steady-state capital stock. When expectations are static, such an approximation can be useful, though it does obscure the interpretation of the coefficients (cf. fn. 22). The reasonableness of this procedure becomes less clear in the case of forward-looking expectations, where the steady-state capital stock changes with the arrival of new information. What is one to make of a steady-state indexed by time? This ambiguity aside, changes in the steady state will necessarily lead to instability in the approximation and, hence, in the estimated coefficients.

The fourth and final caveat pertains to the discount rate. The computation of $E_t\{\Lambda_t\}$ depends critically on passing the expectation operator through the product of the discount rate and the spot marginal revenue product; that is, $E_t\{\rho^s \lambda_{t+s}\} = \rho^s E_t\{\lambda_{t+s}\}$. This operation is permissible when the discount rate is independent of λ_{t+s}, a condition easily fulfilled by our constant ρ but may not be met with more general specifications. However, as we shall see below, some evidence suggests that Λ_t can be approximated linearly, and the sums for the stochastic ρ_{t+s}'s and λ_{t+s}'s computed separately (Abel and Blanchard 1986).

Empirical Results. Closed-Form Forecasting models have generally yielded rather small price elasticities. Estimating equations for quasi-fixed labor and capital with quarterly data, Richard Messe (1980) finds insignificant coefficients on the relative price terms. With a similar specification but annual data, Louis Chan (1984) reports that tax policy has little impact and the cross-equation restrictions between (21) and (24) are rejected. Taxes have a larger effect in the unrestricted model, and a doubling of the investment tax credit for the period 1962–1979 yields an investment elasticity of -0.24 with respect to the user cost. With quarterly data, R. Schramm (1970) reports that the user cost is statistically significant. Benjamin Bernanke (1983) estimates a Closed-Form Model with annual data, and finds that net investment in equipment and structures is responsive to the gross return to capital; the elasticity is approximately 1.60 in the first year. Price effects are smaller. An increase in the investment credit leads to a first year elasticity of -0.68; the comparable elasticity for the real interest rate is -0.20.

Two-Step Forecasting models have also tended to generate small price elasticities. Auerbach and Hassett (1992) find a modest response of investment to the discounted sum of productivity-augmented λ_{t+s} (similar in their model to the discounted sum of q_{t+s}). By contrast, for quarterly equipment investment and a profit-maximizing firm, Roger Craine (1975) reports a large investment elasticity with respect to p_t^I of -0.94. The next two studies are based on multiple equation frameworks of interrelated factor demands under cost minimization. User cost and output elasticities for the long-run capital stock of -0.28 and 0.65, respectively, are obtained by Nadiri and Ingmar Prucha (1990) in their study of annual factor demands of the U.S. Bell System. In contrast to Morrison's results with an Euler Equation model, the elasticities change

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[45] Some applications of the Two-Step Model define λ_t in terms of endogenous variables. While econometrically consistent estimates can be obtained with the predetermined variable(s) in (21), difficulties arise because the paths of these variables implied by the forecasting equations are not necessarily consistent with the path implied by the optimization problem.

little if expectations are static. With quarterly data, Edward Kokkelenberg (1984) reports price and output elasticities that are close to zero. In all of these Two-Step models, there is substantial residual serial correlation, suggesting that the adjustment cost technology does not account for all of the relevant dynamics.

With aggregate time series, Abel and Blanchard (1986) generate a number of interesting results for each of the two steps. Vector autoregressive versions of (21) are estimated with five or seven variables and four quarterly lags and, as the financial cost of capital is stochastic, they approximate $E_t\{\Lambda_t\}$ around mean values for its components, λ_{t+s} and ρ_{t+s}. The difference between linear and quadratic approximations to $E_t\{\Lambda_t\}$ is negligible, and the linear approximation appears to be sufficient for empirical work. A less sanguine interpretation is that, as mentioned above, lagged variables are only modestly successful in forecasting deeply into the future and the addition of the quadratic terms has only a modest impact on an already weak estimator.

Based on $E_t\{\Lambda_t\}$ computed in the first step, the estimated elasticity of investment to current and lagged $E_t\{\Lambda_t\}$ varies from 0.10 to 0.30. When the sums of the ρ_{t+s}'s and λ_{t+s}'s constituting $E_t\{\Lambda_t\}$ are entered separately, the former is insignificant and the latter (defined largely in terms of quantity variables) is highly related to investment spending with an elasticity above unity. The investment model further reveals very large adjustment cost parameters, highly serially correlated residuals, and significant coefficients on output, liquidity, and lagged $E_t\{\Lambda_t\}$'s. These are the same problems that have plagued models with q_t. Thus, the particular solution to the unobservable expectations problem does not appear to be responsible for the poor empirical performance of some investment models.

E. *Summary and Unresolved Issues*

How well have Explicit models addressed the four issues remaining unresolved by the Neoclassical research program (listed in Section I)? In principle, being derived from a formal framework, they solve a number of problems concerning theory, technology, and expectations. In practice, however, Explicit models offer a mixed performance, as the q and Direct Forecasting models are generally less successful empirically than the Euler Equation models. The more favorable results may be due to output variables appearing in Euler Equation models or to the reduction of the unobservable expectations problem to one-period ahead projections, which may be easier to estimate than the long leads appearing in the q and Direct Forecasting models.[46] Regarding the determinants of investment and consistent with the Implicit models, the weight of the evidence clearly points to a modest response of investment to prices and a much greater response to output. Relatively little work has been done on quantifying the effects of autonomous shocks on investment.[47]

The Explicit models suggest a number of directions for future work. While the Benchmark Model is theoretically consis-

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[46] It should be noted that the Euler Equation and Direct Forecasting models do not fully address the unobservable expectations problem (discussed more fully in Section IV) because both calculate expected future variables with forecasting equations assumed to be time-invariant. Only if one maintains that the sample period contains no changes in policy or non-policy factors affecting the stochastic environment will these solutions be strictly valid, though this instability is likely to be less severe for the one-period ahead forecasts in the Euler Equation Model. A significant advantage of the simple q Model (17) is that estimation can proceed even if, during the sample period, the stochastic environment is unstable.

[47] The effect of technology shocks has been explored in the Explicit models of Shapiro (1986c), Auerbach and Hassett (1992), and Chirinko (forthcoming b).

tent, it is incomplete because (14) does not reflect all of the information from the firm's optimization problem. Important progress has been made in some studies reviewed here that incorporate labor requirements, the demand for other factors, or the production and adjustment cost technologies. Using additional information from the optimization problem and analyzing additional margins along which the firm operates will be explored in Sections V.A and V.B.

The benefits of working with Explicit models have been obtained at the expense of relying on a number of simplifying assumptions that yield tractable econometric specifications. Throughout Section III, virtually all models have been based on putty-putty capital, constant geometric depreciation, and internal adjustment costs. These assumptions are controversial, and alternative ways of modeling dynamics arising from the technology will be discussed in Section V.C.

Before considering these topics, we note that the important issue of aggregation has received only passing attention in the survey. This neglect reflects in large part the parallel lack of attention in most studies, though some interesting work on aggregation has been undertaken within the Explicit framework.[48] In a provocative paper, John Geweke (1985) highlights inconsistencies between the behavior of individual firms and alternative aggregate representations. Of course, there is no necessary reason why the individual firm should be the basic unit of analysis. As many policy issues are concerned with aggregates, the "representative firm" used in much investment analysis may be more appropriate. Moreover, in the event that micro equations are more poorly specified or micro data are more poorly measured than their macro counterparts, there may be additional advantages to estimating aggregate relations (Grunfeld and Griliches 1960; Dennis Aigner and Stephen Goldfeld 1974). Comparing estimates from different levels of aggregation is informative, but the appropriate level of aggregation remains an open question.

IV. *The Lucas Critique, Modeling Strategies, and Public Policy*

> . . . the importance of *expectations* has been strongly emphasized by nearly all the model-makers . . . Expectations have to have a known relation to something that is itself known or predictable. Otherwise, the emphasis upon the importance of expectations will serve as a proof of hopelessness for the theory that we are concerned with. (Trygve Haavelmo 1960, p. 10; emphasis in the original)

> Yet the question of whether a particular model is structural is an empirical, not a theoretical, one. If the macroeconometric models [containing equations specified implicitly] had compiled a record of parameter stability, particularly in the face of breaks in the stochastic behavior of the exogenous variables and disturbances, one would be skeptical as to the importance of prior theoretical objections of the sort we have raised. (Lucas and Sargent 1978, p. 56)

A watershed in the modeling of investment behavior occurred in the mid 1970s when Robert Lucas published his often cited, but not always heeded, critique of the prevailing practice for quantifying the effects of alternative policies. He argues that, in formulating plans, economic agents necessarily look into the future, and thus the decision rules guiding their actions depend on parameters describing the expectations of future variables, as well as parameters of taste and technology. Lucas views economic policy as the selection of rules that generate paths of policy variables, rather than the selection of arbitrary paths. Thus, "any change in policy will systematically alter the struc-

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[48] For example, Schaller (1990) reports that the micro adjustment cost parameters are approximately half as large as their macro counterparts in a q Model.

ture of econometric models" (Lucas 1976, p. 126), and the estimated coefficients in (the then current) consumption, wage/price, or investment models could not be considered structural, that is, invariant to alternative policy regimes. The important and damning implication for policy analysis is that these econometric relations will prove unstable in precisely those situations in which they are called upon to analyze proposed policies.

In light of this Lucas Critique (LC), quantitative policy analysis can proceed only if the econometric specification permits the expectation parameters, which will vary with alternative policies, to be identified separately from technology parameters, which are invariant to policy changes. As noted repeatedly in Section II, the estimated coefficients in Implicit models are generally an amalgam of expectation and technology parameters, and thus are vulnerable to the LC. Consequently, much subsequent work, reviewed in Section III, has focused on the modeling and isolation of dynamics arising from expectations.

A further ramification has been a schism between the types of models used in the policy-making and academic communities. During the 1960s and the early 1970s, there existed a unity in the modeling strategies employed by economists in either community. This unity was evident in the close relations between studies published in academic journals and conference volumes and the models used in the evaluation and discussion of policy. These models generally treated optimization problems informally and dynamics implicitly, and the investment models were usually closely related to the Neoclassical framework. The MPS Model was a prominent example—joint development by economists at M.I.T. and the University of Pennsylvania (with the financial support of the Social Science Research Council), use on a regular basis by the Board of Governors, and publication of the investment equations in an academic journal (Albert Ando et al. 1974). The Brookings econometric model (James Duesenberry et al. 1965) was an additional collaborative effort between researchers with interests in both disciplinary and policy issues.

This unity was shattered by the LC. Academic research was subsequently redirected almost exclusively toward Explicit models, while the policy-making community has continued to rely on Implicit models.[49] Does this schism imply that, in contrast to the Marshall quote in Section I, current empirical investment research is no longer able to "throw light on practical issues?"

There are at least three reasons why the LC and the associated role of Explicit models has had so little direct impact on current policy evaluations. First, as initially presented, the LC was "user unfriendly"—identified (incorrectly) with policy ineffectiveness, cast in an unfamiliar technical language, and responsible for placing great demands on computer resources. The LC did not comport well with existing policy-making institutions, human capital, nor the available computing technology, though these should account for only a temporary delay in its ultimate acceptance.

Second, the expectations problem highlighted by the LC has not been addressed adequately. Developed in response to the LC, Explicit models have proven less than satisfactory when confronting the data and are usually quite complicated. These shortcomings weigh heavily on economists engaged in policy making because their success is defined by analyses that can be executed in a timely fashion and absorbed by the policy process. Hence, under the current state of knowledge, minding the LC is of only

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[49] See Lucas and Sargent (1978 and the lively comments) and N. Gregory Mankiw (1990) for additional reasons for disenchantment with large-scale macro models built on Implicit modeling principles.

modest value to the policy-making community, and Haavlemo's skepticism about models placing great "emphasis upon the importance of expectations" appears to be fully appropriate.

Third, the empirical relevance of the LC has been questioned. Persuasive theoretical arguments are necessary, but far from sufficient, for policy makers to take notice. The relevant hypothesis has been stated above by Lucas and Sargent and, in one instance, has been examined by assuming that the volatile fiscal environment of the 1980s reflected an unanticipated change(s) in policy regime. The instability associated with the LC is identified by comparing four investment models, but is not quantitatively important.[50] Informal introspection further suggests that other specification issues—aggregation problems and measurement error—may be more troubling quantitatively than the instability associated with the LC. Absent solutions to the expectations problem and evidence of its relative quantitative importance, the LC may well be considered a second-order effect, and may continue to have only a modest direct impact on policy.

Despite this negative evaluation of the LC as an empirical proposition, it has had and should continue to have a substantial effect on framing research questions and informing policy discussions. With its emphasis on dynamics, the LC threw a particularly stark light on the perennial problems facing investment researchers, and highlighted that the resolution of these issues could only occur by stating assumptions explicitly and deriving and examining empirical implications in terms of tightly parameterized models. The LC was thus the major stimulus for the development of the models discussed in Section III.

What are the advantages of Explicit models for future research? Working within explicit frameworks provides an effective disciplining device that forces a consistent and clear treatment of the issues relevant to firm behavior. At only a theoretical level, however, this discipline is incomplete because a large number of theoretically correct models can be constructed. Econometric models of the firm derived from formal optimization problems and confronted with data provide a means for conducting a *disciplined discourse* that generates productively debatable results and uncovers meaningful answers.[51] The discipline imposed by explicit econometric models is especially important in the face of severe limitations with the data and the lack of critical experiments. Without some guidance from theory, noisy nonexperimental data are generally insufficient to discriminate among competing hypotheses of economic interest. While Explicit models may not produce high R^2's and may fail specification tests, they lead to a systematic accumulation of interpretable evidence, and are the preferred vehicle for furthering our knowledge of economic behavior.[52]

Explicit models mindful of the LC also can have a very substantial indirect im-

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[50] See Chirinko (1988). Using a much different approach, Taylor (1989) arrives at a very similar conclusion. David Hendry (1988) proposes examining the Lucas Critique in terms of superexogeneity, which requires "the weak exogeneity of the conditioning information for the parameters of interest, and the invariance of those parameters to changes in the marginal distributions of the conditioning variables" (p. 133).

[51] Such a discourse must be contrasted with the conversational aspects of economic inquiry noted by Donald McCloskey (1985). What has been lost in that provocative analysis is the recognition that not all "conversations" are likely to be equally useful.

[52] See Summers (1991) for a contrasting opinion. Deriving econometric specifications from formal models in no way implies that the equations must be evaluated only by formal statistical tests. While such tests are informative, other considerations—the economic implications of the parameters, the sensitivity of the empirical results to variations in economic and statistical assumptions, and relations among the residuals, the individual instruments, and economic events—can and should be examined.

pact on public policy. As mentioned above, these models do not substantially affect current policy evaluations, which require well-functioning investment models that conform to "common sense" and generate results immediately useful in the policy process. To date, these criteria have been met most satisfactorily by Implicit models.

However, the prevailing "common sense" and the issues examined by policy makers are ultimately influenced by the manner in which the questions are framed and problems are defined.[53] It is through this process—influenced by Keynes' "academic scribbler of a few years back"—that the LC in particular and Explicit models in general have an unmistakable indirect impact on public policy. The LC underscores the critical relations among technology parameters, expectation parameters, and policy rules. One result of this perspective has been that using fiscal policies to "fine-tune" the economy—a possibility suggested by Neoclassical models cum fixed coefficients—no longer receives much attention. Although a detailed discussion of how these and related ideas came to influence macroeconomic policy making is beyond the scope of this paper, the disciplined discourse associated with Explicit models has played a very important role in introducing new ways of thinking into the policy domain, and should guide future research.

V. *The Research Agenda*

> Experience has shown that each of these three view-points, that of statistics, economic theory, and mathematics, is a necessary, but not by itself a sufficient, condition for a real understanding of the quantitative relations in modern economic life. It is the *unification* of all three that is powerful. And it is this unification that constitutes econometrics. (Ragnar Frisch 1933, p. 2; emphasis in the original)

The preceding review suggests to this author that our understanding of business behavior and investment spending will be advanced by uniting the viewpoints "of statistics, economic theory, and mathematics" in developing Explicit models. This section explores three areas where such a research approach seems particularly promising.

A. *Financial Structure and Liquidity Constraints*

The investment literature has been schizophrenic concerning the role of financial structure and liquidity constraints. Since the earliest econometric studies by Jan Tinbergen (1939), Klein (1951), and Meyer and Kuh (1957), liquidity variables have been included frequently as regressors, and generally have proven very significant. However, the theoretical basis for inserting variables representing finance constraints has been absent largely and, in light of the well-known theorem of Franco Modigliani and Merton Miller (1958), such a development was discouraged.

Recent work has begun to close this gap between theoretical implications and empirical regularities—see the survey by Mark Gertler (1988) and the papers and references collected in R. Glenn Hubbard (1990). In one set of studies, the effects of liquidity on investment spending are assessed with specifications that bear a family resemblance to the following q model,

$$I_t/K_t = \pi_0 + \pi_1 q_t + \pi_2 \ell_t/K_t + u_t, \qquad (25)$$

where ℓ_t is a liquidity variable specified as a flow. A prominent innovation in these studies is that the models are estimated with panel data and, as introduced by Fazzari, Hubbard, and Bruce Petersen (1988), the finance constraints hy-

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[53] For example, see Charles McClure (1984) for an interesting account of the shift in academic thought regarding capital income taxation and its impact on the evolution of tax policy.

pothesis is examined in terms of the pattern of estimated coefficients across classes of firms. In their paper, firms are sorted by retention ratios under the hypothesis that firms retaining a higher percentage of their equity income must face higher costs for external funds. Thus, the π_2 for high retention firms should be statistically different from zero and greater than the π_2 for the low retention and presumably unconstrained firms. These cross-sectional implications are largely confirmed with data from different countries and different sortings of firms (to overcome the potential endogeneity problem with retentions). This approach tests the null hypothesis of a correctly specified q model by the significance of the π_2's, and uses their pattern across firms to suggest the alternative of finance constraints.

A second set of studies takes a similar approach, but examines the finance constraints hypothesis using an Euler Equation similar to (20) supplemented with a borrowing constraint. (See Hubbard and Kashyap 1992; Toni Whited 1992, and references therein.) When this constraint is binding, the associated multiplier enters the error term. This implication is evaluated by the correlation between the instruments and residuals in the overidentified model. Firms believed a priori to be constrained in financial markets tend to fail this specification test, while the remaining firms tend to pass. To highlight an alternative hypothesis, the multiplier is parameterized in terms of variables representing finance constraints.

These recent studies have shed considerable light on the relation between liquidity and investment, and have raised important challenges to the view of frictionless capital markets. However, being too distant from an explicit framework, this evidence is inconclusive. For example, in an Explicit model that reflects the effects of financial structure and liquidity constraints commonly discussed in the literature, it is not necessarily the case that liquidity should appear in a q investment equation. Even though financial market frictions impinge on the firm, q is a forward-looking variable capturing the ramifications of these constraints on all the firm's decisions. Not only does q reflect profitable opportunities in physical investment but, depending on circumstances, q capitalizes the impact of some or all finance constraints as well (Chirinko 1992). This explicit framework can be expanded to yield a specification with the same regressors as (25), but the interpretation of the finance constraints hypothesis is now in terms of structural parameters that are combinations of the π's. For recent panel studies, this reinterpretation proves striking—the monotonic pattern among coefficients across classes of firms is rejected in favor of a U-shaped pattern for the structural parameters representing finance constraints. Moreover, the implied cost of external finance is extremely large, as marginal flotation costs are in excess of \$1 for each \$1 of external finance in several cases.

The concern with an incomplete model weighs less heavily on the Euler Equation studies. Nonetheless, the borrowing constraint is imposed exogenously, and the endogenous variables that parameterize the multiplier—such as cash flow and net worth sensitive to the firm's decisions—are not accounted for explicitly in specifying the econometric equation, thus blurring economic interpretations of the statistical tests.

These results highlight the necessity of adopting an explicit modeling approach. It remains uncertain whether significant liquidity and net worth variables are capturing a structural element heretofore missing in the investment equation or are merely reflecting general misspecification. While the recently generated evidence points to the importance of financial structure and liquidity constraints, their sources and severity remain open questions. Given the critical implications for monetary, tax, and regulatory policies, further work relating investment and financing decisions to explicitly specified capital market frictions is clearly needed.

B. *An Expanded View of the Firm and Its Investment Decision*

The above discussion of finance constraints and the general consideration of Explicit models forces one away from focusing on just the investment equation and toward an expanded view of the firm. The bulk of the studies surveyed here examine only a single quasi-fixed input. Yet, there are many margins along which the firm operates, and the factor demand literature has been plagued by an unfortunate bifurcation. One branch has studied multiple factors of production, estimating production function parameters with much less attention to expectations and dynamic aspects of the technology. These latter two elements have received more attention in the other branch that focuses on investment spending surveyed here. Exceptions to this dichotomization of factor demand studies can be uncovered readily, and suggest the potential connections between the two literatures. Insofar as the variability in investment spending and the recognition of the dynamic aspects of the technology lead to improved estimates, econometric analyses of investment data may prove particularly useful in uncovering technology parameters.

In light of the limited information available to applied econometricians, neither approach is likely to dominate, and they should be viewed as complementary. As highlighted by the optimization problem in Section III.A, the behavior of a firm with one variable and one quasi-fixed input is characterized by four conditions—the production/adjustment cost technology, the first-order condition for the variable input, and the Euler and transversality conditions for the quasi-fixed input. Empirical studies reported here and elsewhere estimate various subsets of these conditions, and it is usually difficult to impose the information from the transversality condition. As shown in the derivation of the Explicit Benchmark Model, the q equation provides a tractable way of introducing this information and, in contrast to the Direct Forecasting models, can be implemented under a very general set of circumstances. Because the Euler Equation and q models are alternative ways of solving the unobservable expectations problem and are derived from the same optimization problem, it is natural to view these two methods, along with the technology and the first-order condition for the variable input, as complementary parts of an econometric system. This approach has enjoyed some initial econometric success (Chirinko forthcoming b).

The brief discussion in this subsection by no means exhausts the number of interesting and important issues that should be addressed with Explicit models. The volatile behavior of inventory investment and its interaction with fixed investment and pricing decisions, the impact of public and R&D capital, and the endogeneity of depreciation and utilization could be analyzed profitably in extended versions of the models in Section III. The economic environment in which the firm operates could be broadened to include both the supply of, as well as the demand for, capital goods, an extension that would begin to incorporate general equilibrium effects usually omitted in empirical work. Lastly, recent studies assessing the incidence of taxes and unifying the fields of fluctuations, growth, and development rely heavily on the type of technology parameters that can be obtained from explicit econometric models.

C. *Additional Dynamics*

As discussed throughout the survey, a fundamental issue in investment research is the translation of the demand for the stock of capital into a demand for the flow of investment. The frequent empirical significance of current and lagged quantity variables suggests that these dynamics are very important for understanding investment behavior. Models reviewed in Section III attempt to solve this translation problem by relying on internal adjustment costs that are symmetric, separable, and convex. The latter characteristic has been especially controversial (Rothschild 1971), and may be the reason for the poor empirical performance of some models. External adjustment costs provide a more plausible justification for the convexity assumption, but have not been used as the basis for econometric work.

The most frequently used alternative to adjustment costs emphasizes the delayed responses between the decision to invest—as represented by the placement of an order—and the eventual delivery of, expenditure on, or increment to the productive capital stock.[54] Various aspects of these delivery, expenditure, and gestation lags have been estimated in the literature, and they are the basis for the dynamics appearing in many of the Implicit models reviewed in this survey. Incorporating these lags into Explicit models is relatively straightforward theoretically, but usually amplifies the unobservable expectations problem. There has been some empirical work with expenditure lags with Closed-Form models, but this area is relatively unexplored.[55]

Recent research explores a number of promising ways of entering dynamics into the optimization problem. To capture differences between short-run and long-run supply elasticities, Rosen and Robert Topel (1988) add the *change* in I_t as an argument in the adjustment cost technology, thus permitting led and lagged investment to enter the Euler Equation and expanding the dynamics in the econometric specification. An important characteristic of the capital accumulation decisions that has not been considered fully here is that investment is partly or fully irreversible. An emerging literature examines the investment dynamics that arise from irreversible investment and the ongoing resolution of uncertainty that, in combination, give value to postponing investment decisions similar to a financial call option.[56] These factors create an opportunity cost for investing today (as opposed to postponing investment and learning more about prospective returns), and thus add a wedge between the benefits and costs that characterize optimal investment policy—cf. (12d).

Models with "lumpy" and "incremental" investment (the latter the focus of this survey) have been developed, and the impact on econometric specifications depends whether the wedge, usually a function of the proportional variance of the stochastic process governing unknown exogenous variables, is fixed

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[54] See Thomas Mayer (1960) for further discussion of lead times involved in acquiring capital.

[55] Taylor (1982), Abel and Blanchard (1988), and Sumru Altug (1989) successfully estimate Closed-Form models with expenditure lags, but their models restrict the role of prices.

[56] See the recent survey by Pindyck (1991). Joseph Zeira (1987) analyzes a somewhat different model in which the resolution of the information problem is endogenous. Including endogenous depreciation (which will attenuate the effects of irreversibility) and putty-clay capital within this analytic framework should prove particularly informative.

or time-varying. If the variance parameter is stable, then there will be no appreciable effect on estimated investment equations. As with many econometric relations, parameter instability will lead to model instability. Ascertaining whether such shifts have occurred is quite difficult—does a large increase in output price represent a shift in or an extreme realization from the underlying stochastic process? Nonetheless, this research effort highlights a number of key parameters and margins, and should form the basis for interesting and important econometric work.[57]

VI. *Summary and Conclusions*

> No matter how precisely the coefficients of any particular specification may appear to be estimated . . . estimating alternative models to study the same question can be a useful reminder of the limits of our knowledge. (Feldstein 1982, p. 831)
>
> Estimation of investment functions is a tricky and difficult business and the best posture for any of us in that game is one of humility. (Eisner 1974, p. 101)

This study has offered a critical review of the literature on business fixed investment spending, and has assessed the current state of knowledge and future research agenda.[58] To place some structure on this vast literature, the survey has been organized according to two principles. The first sorted models by whether dynamics were introduced into the econometric equation implicitly or explicitly. Benchmark models were developed for each category, and provided the basis for all of the models discussed in this survey. The second organizing principle focused on the four important issues (listed in Section I) that have been faced repeatedly by investment researchers. A number of these issues have been addressed reasonably well, and most recent models are theoretically consistent and isolate the effects of expectations and technology on the econometric equation. Such success has been purchased partly by maintaining a number of uncomfortable restrictions, and the research agenda aims to expand our view of the firm and the margins along which it operates. A final issue concerns the relative importance of prices, quantities, and shocks as determinants of investment. While there is clearly no uniformity in the results and the role of shocks remains to be assessed, it appears to this author that, on balance, the response of investment to price variables tends to be small and unimportant relative to quantity variables.

The fundamental problem facing the applied econometrician is how to generate and interpret econometric evidence when the available data are nonexperimental and have limited and noisy variation. The most direct solution would be to obtain better data, but collecting comparable data for firms is a difficult and expensive task. An alternative research strategy would use sophisticated statistical techniques to attempt to correct for various difficulties. As these procedures are based frequently on large samples of spotlessly measured data, doubts exist about their usefulness for applied work. Statistical research would be particularly informative if it focused on the small sample properties of various estimators, highlighting their robustness to nonclassical measurement error and other sources of misspecification that plague all econometric equations.

As has been argued throughout this survey, exploiting the information and

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[57] For example, for heterogeneous firms facing irreversible investment and idiosyncratic and aggregate uncertainty, Giuseppe Bertola and Ricardo Caballero (1991) derive and estimate an aggregate equation in which investment adjusts gradually, thus generating the same qualitative behavior implied by convex adjustment costs.

[58] For additional details and an extended bibliography, see the monograph (Chirinko forthcoming a) that complements this survey.

restrictions provided by theory is likely to be the most productive approach. Clearly there is a tension between the restrictions to maintain and those to test. These and other questions will arise in empirical applications, and progress will occur only after comparing the results and assumptions from many different models. No single study, regardless of the generality of the specification nor the richness of the data, will deliver "the" definitive test. As a result, the disciplined discourse fostered by an explicit modeling approach is needed for interpreting various studies and extending our understanding of firm behavior. Despite these decided benefits, our review of previous investment studies and the numerous caveats mentioned throughout this survey remind us of the "limits of our knowledge" and the degree of "humility" appropriate when interpreting all econometric work.

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