Time to Build Capital: Revisiting Investment-Cash Flow Sensitivities

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Abstract

A large body of empirical work has established the significance of cash flow in explaining investment dynamics. This finding is further taken as evidence of capital market imperfections. We show, using a perfect capital markets model, that time-to-build for capital projects creates an investment cash flow sensitivity as found in empirical studies that may not be indicative of capital market frictions. The result is due to mis-specification present in empirical investment-q equations under time-to-build investment. In addition, time aggregation error can give rise to cash flow effects independently of the time-to-build effect. Importantly, both errors arise independently of potential measurement error in q. Evidence from a large panel of U.K. manufacturing firms confirms the validity of the time-to-build investment channel.

JEL classification: D21; E22; E32; G31.

Key words: Investment; Capital market imperfections; Time-to-build.

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1 Introduction

Investment in fixed capital is one of the most important and volatile components of aggregate activity. Understanding investment dynamics is central to the study of aggregate fluctuations. In the neoclassical theory of firm investment with adjustment costs, the firm's market value and investment respond simultaneously to signals about future profitability as encoded in Tobin's q. In this theory, Tobin's q, defined as the expected value of the firm relative to its capital stock becomes a summary statistic for investment. Nevertheless, despite its theoretical appeal the empirical performance of the q theory has been rather disappointing. In contrast to the predictions of the theory, various measures of internal funds such as profits or cash flow are significant in explaining corporate investment and the responsiveness of investment to fundamentals is weak. This sensitivity of investment to internal funds is further taken as evidence of capital market imperfections that disturb the firm's investment schedule from the frictionless neo-classical benchmark. This paper uses a neoclassical investment-q model with time-to-build and time-to-plan features for capital and revisits this evidence. We provide a new explanation for the emergence of cash flow effects in empirical investment-q equations that relies on an important technological aspect of capital production.

Time-to-build and time-to-plan are key technological features of investment. A variety of survey (Montgomery (1995) and Koeva (2000)) and firm level (Koeva (2001), Del Boca et al. (2008)) evidence suggests that these technological constraints are important at the firm level. This evidence indicates that the time required for the installation of new equipment and structures ranges from 3 to 4 quarters for equipment and 2 to 3 years for non-residential structures. But as we demonstrate in this paper, the typical investment-q equation that serves as the benchmark for evaluating the capital market imperfections hypothesis, is usually not robust to the presence of time-to-build investment. When time is required to build new capital q is no longer a sufficient statistic for investment. This result arises because under time-to-build an additional state variable significantly affects optimal investment decisions. Investment consists of new and partially-finished projects that have not yet become productive capital. In addition to q the sum of current expenditures on existing incomplete projects belongs to the right hand side of the investment regression. In other words, when the firm decides—on the basis of new information about future investment opportunities—how many new projects to initiate, past projects already under way influence that decision, i.e. they constitute a state variable for this decision. The perfect capital markets model we use allows us to characterize this state variable analytically and show how it induces specification error in the typical investment-q equation. More importantly, we show this state variable is strongly correlated with cash flow and thus when not included among the right-hand-side variables of the regression, induces a positive investment cash-flow sensitivity that is nevertheless not indicative of capital market imperfections.

We use the model to calibrate and simulate an industry to the aggregate U.S. manufacturing sector. The specification error we identify renders q an insufficient summary statistic is the primary driver of cash flow effects in our simulated investment-q regressions. Our results closely corroborate findings recently reported in Eberly et al. (2008) although (as explained below), in contrast to theirs, our findings are free of measurement error in q. Nevertheless as we demonstrate, measurement error magnifies the specification error we identify. Further, our model provides an explanation for the emergence of lagged investment effects in empirical investment-q regressions, in addition to cash-flow effects. The importance of lagged investment effects is a largely overlooked empirical regularity, since most of empirical work focuses almost exclusively on the role of cash flow. But as Eberly et al. (2008) note: "Both cash-flow and lagged-investment effects have been found in virtually every investment regression specification and data sample." In our study—as in Eberly et al. (2008)—we show that the lagged investment rate is an important determinant of current investment because it proxies for an omitted state variable. In Eberly et al. (2008) simulations, lagged investment proxies for a regime-switching component in a firms' demand schedule. In the present model with time-to-build, lagged investment has a different structural interpretation, capturing time-to-build effects for the construction of capital.

We further investigate whether our model can reproduce cross sectional differences in investment cash-flow sensitivities reported in the majority of empirical studies that test for capital market imperfections (see for e.g. Fazzari et al. (1988), Gilchrist and Himmelberg (1995), and the survey by Hubbard (1998)). These studies find that firms which are thought *a-priori* to be more vulnerable to imperfections in capital markets, e.g. small, young, with no dividends payout firms, exhibit higher investment cash flow sensitivities compared to firms that are thought to have ample access to external finance, e.g. large, old, dividend distributing firms. We show that the model is capable of reproducing this empirical regularity as long as the former group of (constrained) firms have longer time-to-build investment schedules compared to the latter group of (unconstrained) firms. For this purpose we bring to light evidence from large samples of U.S. (Compustat) and U.K. (Datastream) manufacturing firms that strongly suggests constrained firms to have longer time-to-build investment schedules compared to unconstrained firms.

The presence of mis-specification under time-to-build begs the question of whether and how we can mitigate it when undertaking empirical work within the q framework. We show that we can approximate the omitted state variable with two readily available variables, namely the lagged investment rate and the growth rate of the capital stock. We evaluate the usefulness of this approximation for empirical work in our simulated environment and find that it performs almost as well as its theoretical counterpart, nearly eliminating the cash flow effect from the investment regression. We then test the predictions of the theoretical model in a large panel of U.K. manufacturing firms and find results that are remarkably consistent with the proposed time-to-build channel. When we include the two variables above as right-hand-side regressors in the empirical investment-q equations we find a significant improvement in the fit of the regression equations. More importantly, the inclusion of these controls nearly eliminates both the cash flow sensitivity of investment and the cross sectional difference in the cash flow coefficients. Finally, *independently* of the time-to-build effect above we show that a cash flow effect can emerge in an investment-q

equation when researchers estimate an investment-q regression using annual data—a practice followed in the majority of studies—that are aggregated from more frequent factor input decisions. This time or temporal aggregation error has been highlighted in the context of capital and labor adjustment cost estimates by Hall (2004) but as far as we know the implications in an investment-q framework have not been explored.

Recent work by Erickson and Whited (2000), Gomes (2001), Cooper and Ejarque (2003), Alti (2003), Cummins et al. (2006), Abel and Eberly (2003), also cast doubt on the validity of investment cash flow sensitivities as an indicator of capital market imperfections. Erickson and Whited (2000), Gomes (2001) and Cummins et al. (2006) stress that cash flow effects may arise because Tobin's q is measured with error. Cooper and Ejarque (2003) emphasize market power that creates a divergence between average and marginal q while in Alti (2003) Tobin's q is a noisy measure of fundamentals and cash flow is highly informative about long-run profitability. Finally, in Abel and Eberly (2003) cash flow effects arise as a result of specification error induced by changes in the user cost of capital. Yet, our contribution is rather different from all the above. First, in time-to-build, we provide a new and important channel for the emergence of significant cash flow effects in investment-q regressions. Importantly, this channel receives considerable support from the data. Second, in contrast to the studies above our findings do not involve any mis-measurement between average and marginal q and thus are not driven by measurement error.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 discusses the solution and calibration. In section 4 results from the simulated version of the model are presented. Section 5 concludes.

2 The Model

We use a model developed in Tsoukalas (2003) suitable for analyzing firms investment decisions in a time-to-build environment. A similar framework has been employed by Zhou (2000) to explain aggregate investment dynamics. The following subsections explain the components that are essential to the framework.

2.1 Firms

2.1.1 Technology

We model an industry which is populated by a continuum of risk-neutral infinitely-lived firms. Firm j produces output, using the following decreasing returns to scale Cobb-Douglas technology:[1]

$$y_{jt} = A_t \omega_{jt} F(K_{jt}, M_{jt}, L_{jt}) = A_t \omega_{jt} K_{jt}^{\alpha} M_{jt}^{\gamma} L_{jt}^{\nu} \quad \gamma + \alpha + \nu < 1$$

where A_t is an aggregate (common) and ω_{jt} an idiosyncratic productivity shock. K_{jt} is capital, L_{jt} is the labor input and M_{jt} is the stock of materials.

The investment technology requires time to build new capital. Specifically, it takes J-periods (stages) to build new productive capacity. This technology implies that in any given period t, firms initiate new projects, s_{Jt}, and complete partially finished projects, s_{it}, $i \neq J$ at stage i. This assumption intends to capture the design and construction (delivery) stages that exist in undertaking investment projects in plant and equipment as suggested by Kydland and Prescott (1982). The assumptions of this time-to-build (TTB) technology are summarized below:

$$s_{it} = s_{i-1,t+1} \quad i = 2, ...J \tag{2.1}$$

$$K_{t+1} = (1-\delta)K_t + s_{1t} \tag{2.2}$$

$$I_t = \sum_{i=1}^{J} \varphi_i s_{it} \tag{2.3}$$

with $0 \leq \varphi_i \leq 1, \quad i = 1, 2, ...J$, and $\sum_{i=1}^{J} \varphi_i = 1$. To clarify notation, s_{Jt} denotes new projects at time t, $s_{J-1,t}$ denotes projects initiated at time $t-1$, that are $J-1$ periods away from completion

[1]Decreasing returns to scale are necessary for firm size to be well defined. Otherwise firm size is indeterminate and the entrepreneurial sector reduces to just a single producer.

at time t, and so on. The last stage project, s_{1t} yields productive capital in the following period. The parameters φ_i determine the fixed fraction of resources allocated to projects that are i periods away from completion, or equivalently the proportion of the value of the project put in place in period i. I_t denotes total investment expenditures at time t and depends on the resources expended for the different incomplete projects. Finally, the capital stock depreciates at rate δ.

New investment projects are subject to adjustment costs. It is assumed that firms face a quadratic cost of adjustment function for investment in new projects, i.e.,

$$G(s_{J,jt}, K_{jt}) = \frac{\eta}{2}(\frac{s_{J,jt}}{K_{jt}} - \delta)^2 K_{jt} \tag{2.4}$$

where the parameter η governs the curvature of G.[2] This function has all the usual properties, i.e., it is convex, with a rising marginal adjustment cost. It also implies a zero adjustment cost in the steady state.

2.1.2 The firm's problem

The firm chooses new investment projects, $s_{J,jt}$, materials orders, d_{jt}, and labor input, L_{jt}, in order to maximize firm value:

$$\max_{L_{jt}, s_{J,jt}, d_{jt}} E_0 \sum_{t=0}^{\infty} \beta^t div_{jt}$$

where div_{jt} denote dividends. To conserve space a detailed description of the maximization problem is described in Appendix 1. Re-arranging the first order necessary condition for new projects, $s_{J,jt}$ and assuming that projects require 3 periods for completion (i.e. $J = 3$) gives the equation for optimal investment rate:

$$\frac{I_{j,t}}{K_{j,t}} = \varphi_3\Bigg(- \frac{1}{\eta}(\varphi_3 + \beta\varphi_2 + \beta^2\varphi_1) + \delta\Bigg) + \varphi_3\frac{1}{\eta}\beta^2 E_t(q_{j,t+2}) + \sum_{i=1}^{2} \varphi_i \frac{s_{i,jt}}{K_{j,t}} \tag{2.5}$$

Optimal investment is a function of future expected marginal q (i.e. the shadow value of installed capital), reflecting the fact that capital will become productive with a lag and an additional state

[2] An alternative characterization of the adjustment cost function is to assume that the cost is paid at the time when resources on projects are expended, i.e., $G(s_{1,jt}, ...s_{J,jt}, K_{jt}) = \sum_{i=1}^{J} \varphi_i \frac{\eta}{2}(\frac{s_{i,jt}}{K_{jt}} - \delta)^2 K_{jt}$. We choose to work with the simpler form (2.4) because of the analytical simplicity. We have experimented with this alternative adjustment cost function with very similar results.

variable that represents part of the investment outlays already underway. Thus in this environment q ceases to be a sufficient statistic for investment.

3 Solution

The equilibrium of the model is characterized by a set of Euler equations along with the Kuhn-Tucker conditions for the equality constraints and the given initial values for the state variables. This equilibrium is a set of non-linear equations and an analytical solution is infeasible to compute. An approximate solution is calculated by using a second order approximation method around the non-stochastic steady state of the model. The second order Taylor approximation, as described in Schmitt-Grohe and Uribe (2004), can be readily used to calculate the decision rules for new projects, materials orders and labor. Appendix 1 describes the essential computational details of the solution.

3.1 Calibration

We calibrate the model using a baseline set of parameter values described in Table 1 using quarters as the time unit. We calibrate the parameters needed to simulate our model to several characteristics of the U.S. manufacturing sector. Appendix 2 reports in detail the various sources we have used for the calibration exercise. We briefly comment on the calibration of the TTB technology (i.e. values for φ_i's) since this is the key element of the model and the focus of this study. In the baseline calibration we assume that an equal amount of spending takes place over three quarters, namely $\varphi_1 = \varphi_2 = \varphi_3$. A body of empirical evidence supports this assumption. In the robustness section 4.5, we also consider several different values for the time-to-build technology given evidence from various countries that suggest an unequal pattern of spending over the life of capital projects.

4 Results

In this section, we present results from the calibrated version of the model. The (approximate) decision rules for the model's variables are simulated and artificial data are generated. Using the artificial data we create a panel of firm level data. We generate a panel of 1000 firms observed over 20 years and demonstrate that a significant cash-flow effect can arise even in a model with perfect capital markets.

4.1 Investment-q regressions

In this section we use the artificial panel to estimate investment-q regressions augmented with cash flow. We note that empirical studies, typically rely on annual firm level (e.g. Compustat or Datastream) data, whereas our model is calibrated quarterly. We first present brief results to build intuition using our quarterly model and then aggregate our model to correspond to the annual frequency. This allows to study the role of time aggregation.

To demonstrate the inference-problem associated with reduced form investment equations under TTB, we estimate an OLS regression on the artificial data,

$$\frac{I_{j,t}}{K_{j,t}} = \alpha + b_1 E_t(q_{j,t+2}) + b_2 \frac{\pi_{j,t}}{K_{j,t}} + \varepsilon_{j,t} \tag{4.1}$$

where the left-hand-side (LHS) variable is the investment rate, and the right-hand-side (RHS) variables are the expected marginal q along with the profit rate and j indexes firms. Expected marginal q is the correct statistic for capturing future investment opportunities under TTB because new investment projects become productive after three periods (see equation 2.5). This is a typical empirical investment equation except that Tobin's q is usually taken as a proxy for the un-observed marginal q. A notable exception is Gilchrist and Himmelberg (1995) who construct a proxy for marginal expected q. We also note that a typical empirical equation also includes a firm specific effect. In our model however firms can only differ in the history of shocks they receive so there is not any ex-ante firm-specific heterogeneity. We contrast this equation with the investment equation 2.5 and note that (ignoring the constant and error term) the correct specification under TTB includes $\sum_{i=1}^{2} \varphi_i \frac{s_{i,jt}}{K_{j,t}}$ as a RHS variable. This sum is the part of investment that has responded to old information (about productivity) and is therefore a state variable. The question is whether omitting this variable invalidates the inference drawn on the role of profits from an empirical equation like (4.1). The answer is affirmative if the profit rate is correlated with $\sum_{i=1}^{2}\varphi_i\frac{s_{i,jt}}{K_{j,t}}$. This turns out to be the case with persistent productivity shocks.[3] The intuition is as follows. Suppose that at some time in the past a favorable productivity shock caused a surge in new projects. As time elapses these new projects come closer to completion time and if the shock is persistent then at time t there will be a series of outstanding projects, $s_{1t}s_{2t}, ..., s_{J-1,t}$. Moreover with persistent shocks current profits will also reflect the same past productivity shocks that caused the firm to initiate new projects and are now exactly those projects above that have moved closer to completion. Therefore current profits are correlated with each of these previous capital projects and hence their sum. This implies that profits will proxy for this state variable in an investment-q regression. Of course if q was a sufficient statistic for total investment (it is a sufficient statistic only for new projects, s_{Jt}) then profits would not be significant in a regression with investment and q. Table 2 reports the results from estimating equation (4.1) on our artificial panel of firms. We can observe that the profit rate coefficient, b_2 is positive and statistical significant, even though our model was designed without capital market imperfections. Therefore, the profit rate appears as a significant variable and improves the fit of the equation as it proxies for a relevant omitted RHS variable. It is also important to stress that any role for this variable in these regressions does not arise as a result of measurement error since we are using the appropriate (marginal) measure of q. Instead the explanatory role of the profit rate arises as a result of specification error due to TTB for investment.[4]

4.2 Quantifying specification and time aggregation error

In this section we have two goals. First, to explore whether time aggregation can spuriously assign a role to cash flow independently of the specification error that is created as a result of TTB. Second,

[3] To conserve space we present a set of correlations in Table 4. For the case examined here the correlation between the two series is equal to 0.83.

[4] As expected, if we estimate the correct specification (2.5) we find no role for the profit rate. We do not report these results for brevity but they are available upon request.

to investigate precisely how the TTB specification error generalizes in the annual framework. We therefore aggregate our artificial data to correspond to the same annual measures used in empirical studies and make the investment equations directly comparable. We highlight two findings: (i) we identify a time aggregation error that can give rise (independently from the specification error due to TTB) to cash flow effects in investment regressions with annual data and (ii) we demonstrate that the TTB specification error generalizes in the annual environment.

We re-estimate the empirical investment equation specified in section 4.1 in the annual environment (for convenience we drop the firm-specific subscript j), for $J = 1, 2, 3, 4$. Here as in the previous section J refers to TTB in quarters, so the maximum length for the construction of capital we consider is one year.

$$\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a \tag{4.2}$$

4.2.1 Time aggregation error

In Appendix 3 we discuss in detail the aggregation of the model to the annual frequency and characterize the error that arises in this environment. The important insight is that time aggregation gives rise to a non-zero term in the investment regression that is correlated with the profit rate. This implies a small (but significant) cash flow effect when this term is omitted from the regression. Table 3 reports the results from estimation of (4.2). Note that adding the profit rate to the regression yields a positive and statistical significant b_2 coefficient (bottom panel). To illustrate the role of time aggregation in producing a cash flow effect we focus on the $J = 1$ case. We note from Table 2 that for $J = 1$ in the quarterly model, $(\frac{\pi_t}{K_t})$ has no explanatory power. This follows from the fact that for $J = 1$ there is no investment outlay that refers to a decision taken previously $(s_{Jt} = ... = s_{1t} = I_t)$ and hence no omitted RHS state variable. Even though the profit rate will be correlated with investment rates, its forecasting role for future investment opportunities is properly accounted for by marginal q. Thus any role for the profit rate in Table 3 in the $J = 1$ column can be solely attributed to the time aggregation error which gives rise to an extra term equal to $\left(\frac{1}{K_t^a}\sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}\right)$, that is correlated with the profit rate and hence generates a small positive profit rate coefficient as explained above.

4.2.2 Specification error

On the other hand, the specification error that arises due to the TTB nature of investment can be seen by examining the first order condition (FOC) for optimal investment when $J > 1$. For example, summing the FOC for optimal investment (where $k = 1, 2, 3, 4$ indicates quarters) over quarters for $J = 3$ we get,

$$-4(\varphi_3 + \beta\varphi_2 + \beta^2\varphi_1) - \eta\left(\sum_{k=1}^4 (\frac{s_{3t,k}}{K_{t,k}} - \delta)\right) + \beta^2 \sum_{k=1}^4 E_k q_{t,k+2} = 0$$

which after straightforward manipulations and using (2.3) we can write as,

$$-\varphi_3(\varphi_3 + \beta\varphi_2 + \beta^2\varphi_1) - \frac{\eta}{4}\left(\sum_{k=1}^4 (\frac{I_{t,k}}{K_t^a} - \delta)\right) + \frac{\eta}{4}\left(\frac{1}{K_t^a}\sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}\right)$$
$$+\frac{\eta}{4}\sum_{k=1}^4 \frac{\sum_{i=1}^2 \varphi_i s_{it,k}}{K_{t,k}} + \beta^2\varphi_3 \frac{\sum_{k=1}^4 E_k q_{t,k+2}}{4} = 0$$

Re-arranging this equation to bring $\frac{I_t^a}{K_t^a}$ on the left hand side of the equation we finally arrive at,

$$\frac{I_t^a}{K_t^a} = constant + \left(\frac{1}{K_t^a}\sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^4 \frac{I_{t,k}}{K_{t,k}}\right) + \sum_{k=1}^4 \frac{\sum_{i=1}^2 \varphi_i s_{it,k}}{K_{t,k}} + \varphi_3 \frac{1}{\eta^a}\beta^2 q_t^a \tag{4.3}$$

where we have used, $\sum_{k=1}^4 \frac{I_{t,k}}{K_t^a} = \frac{I_t^a}{K_t^a}$ and $q_t^a = \frac{\sum_{k=1}^4 E_k q_{t,k+2}}{4}$. This is the annual counterpart to equation (2.5) and we see that there is an additional RHS variable that reflects the TTB technology in this version as well. This is given by $\sum_{k=1}^4 \frac{\sum_{i=1}^2 \varphi_i s_{it,k}}{K_{t,k}}$ which is a summation (over quarters per year) of the omitted state variable in equation (2.5), i.e. a linear combination of the latter. The annual profit rate, $(\frac{\pi_t^a}{K_t^a})$, will be the sum of the corresponding quarterly rates and it will be correlated with this state variable since both are sums of the corresponding quarterly measures. Therefore since the profit rate is correlated with the key omitted state variable and the investment rate (see Table 4, lower bottom) regressing $\frac{I_t^a}{K_t^a}$ on q_t^a and the profit rate will result in a statistical significant role for the latter. But this is merely reflecting the omission of an explanatory variable from the RHS of the regression.[5] Since in our model capital markets are perfect, any role for profits must result from this mis-specification.

4.2.3 Incorrect inference in the investment-q regression under TTB

We now discuss the results reported in Table 3. In the top panel we demonstrate the incorrect inference drawn for the magnitude of the adjustment cost parameter, η^a (imposing $b_2 = 0$). Using the estimated coefficient on q as the basis for obtaining an estimate of the adjustment cost parameter—i.e. computing $\eta^a = \frac{1}{b_1}$, a practice typically followed in the literature—would lead a researcher to infer an estimate considerable higher compared to the true value. Note that in this case the magnitude of the overestimation of η^a ranges from roughly 7% for $J = 1$ to 22% for $J = 4$ (top panel, Table 3). Thus lengthier time-to-build technology produces adjustment cost estimates that imply slower adjustment speeds for capital. The reason for the incorrect inference based on the coefficient of q is the fact that the true coefficient of the latter is scaled by φ_J (see equation 4.3) and thus the estimated regression coefficient is an amalgam of φ_J and η^a. Therefore as φ_J falls with the length of the TTB so does b_1, the regression coefficient on q. The source of this overestimation lies in the fact that in this simple investment-q framework it is not possible to separately identify the TTB parameters and the adjustment cost parameter from the estimated coefficient on q.[6] Interestingly, Barnett and Sakellaris (1999) and Del Boca et al. (2008) using US and Italian annual firm level data respectively, provide evidence consistent with our findings, reporting signifi-

[5]The estimated coefficients in Table 3 reflect both the time aggregation and specification error. However, the former's contribution to the b_2 estimates for $J > 1$ is extremely small. This can be shown by using $\sum_{k=1}^{4} \frac{I_{t,k}}{K_{t,k}}$ instead of $\frac{I_t^a}{K_t^a}$ as the LHS variable in (4.3) thus eliminating the aggregation error. The resulting estimated coefficients are nearly identical to those shown in Table 3 and are not reported but are available upon request.

[6]We can also examine the true bias in the q coefficient this regression framework generates in the hypothetical case that a researcher knows the true values of the TTB parameters. This information is summarized in the Appendix on inference and biases under TTB investment. We note in this case there is an upward bias in the q coefficient (equivalently a downward bias in the magnitude of η^a) due to the fact that the expected value of b_1 moves in proportion with the coefficient of the omitted variable (see Appendix 3).

cantly lower adjustment cost parameter estimates when TTB investment is allowed for. While our results suggest a potential explanation for the reported low q estimates in the literature there is one caveat. This is due to the fact that empirical work uses Tobin's q instead of the unobserved marginal q. Thus it is not straightforward to compare our simulated results with empirical findings. As Erickson and Whited (2000) demonstrate measurement error in q will also lead to coefficient estimates that are biased towards zero.

We now focus on the role of cash flow in this TTB environment which is the main goal of this study. The bottom panel of Table 3 includes the profit rate as an additional RHS variable. Two findings are worth noting. First, augmenting the regression with the profit rate generates a positive and statistically significant coefficient on the latter. Second, and more importantly the inclusion of the profit rate improves the fit of the equation as evidenced by the increase in the adjusted R^2 values reported in the bottom panel. In addition, the coefficient of the profit rate increases as the TTB length increases. For example, as we move from $J = 2$ to $J = 3$ the profit rate coefficient rises from 0.22 to 0.29. In other words, the regression results indicate a higher sensitivity of investment to profits as the length of TTB increases. This follows from standard econometric results since marginal q, profit rate and the omitted state variable are strongly correlated (e.g. Judge et al. (1985), p.858); accordingly the mean value of the profit rate coefficient reported in Table 3 will vary proportionately with the true coefficient of $\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} \varphi_i s_{it,k}}{K_{t,k}}$ with a factor of proportionality that is determined by the correlation of the RHS regressors with the omitted state variable and vary inversely with the true coefficient on q which falls with φ_J as J increases (Appendix 3 provides the details). The results of Table 3 clearly illustrate that the omission of the TTB state variable generates a large bias of the profit rate coefficient since the true coefficient on this variable is zero. This bias ranges from 0.22 to 0.35 and leads to incorrect inferences on the role of cash flow in the investment-q regression framework.

We now turn to the question of whether our model can replicate the different cross sectional investment-cash flow sensitivity reported in the majority of empirical studies that test the imperfect capital markets hypothesis.

4.3 Cross sectional implications

In this section we discuss some potential cross sectional implications of TTB. Our model predicts that the cash flow effect will be present across different cross sections of firms as long as all cross sections share the same TTB technology. This will be true for example for small vs. large firms. On the other hand, studies that seek to test for capital market imperfections typically report investment-cash flow sensitivities that vary significantly by cross section (see Fazzari et al. (1988) or Gilchrist and Himmelberg (1995)). Evidently our model predicts the same cash flow sensitivity for either small or large firms if they are subject to the same TTB technology. The length for TTB however will crucially depend on the type of investment that firms undertake. Consider for example two firms (A and B) that are identical in all other respects except that firm A invests proportionally more in structures and less in equipment compared to firm B. The available evidence discussed in Appendix 2 suggests that TTB is considerably longer for structures than it is for equipment. Therefore firm A will be characterized by a longer TTB technology compared to firm B. The results from Table 3 then predict a larger cash flow coefficient for firm A compared to firm B. Is it then likely that differences in TTB technologies exist among different groups of firms in such a way as to be able to capture the differences in investment-cash flow sensitivities reported in the literature? For this purpose we bring to light evidence that strongly suggests TTB varies by firm size. We have information from a large sample of Compustat and Datastream firms (U.S. and U.K. manufacturing sectors respectively) that allows us to compute investment spending in structures and equipment. Table 5 reports the mean ratio of structures to equipment investment for small and large firms classified as such using the same classification criteria adopted by existing empirical work. The robust feature of Table 5 is that small firms exhibit higher structures to equipment spending ratios compared to large firms and in some cases these differences are also statistical significant at the 5% and 10% significance level.[7] Consequently small firms may be characterized by longer TTB periods for their capital expenditures. The implication is that small firms should exhibit higher sensitivity to profits compared to large firms. Even *one quarter difference* in the TTB technology can produce significant differences in investment–profit sensitivities between firms as Table 3 illustrates. The model is thus capable in replicating the cross sectional differences in investment cash-flow sensitivities documented in empirical work by exploiting differences in TTB technology as suggested by the evidence above.

4.4 Implications for empirical work

In light of our findings it is worthwhile investigating the empirical implications and offer some recommendations for empirical work. Specifically we would like to know what particular information from the data can be used in order to estimate a correctly specified investment-q regression under TTB investment. For the remainder of the analysis we focus on the case $J = 3$. It is quite straightforward to generalize for any J. The key state variable that creates the link with cash flow (or more generally any profitability measure) is given by,

$$\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} \varphi_i s_{it,k}}{K_{t,k}}$$

In Appendix 3 we show that the state variable above can be approximated by the following expression,

$$\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} \varphi_i s_{it,k}}{K_{t,k}} \approx \sum_{k=1}^{4} \left(\frac{I_{t-1,k}}{K_{t,k}} - \varphi_1 \left(1 - \frac{(1-\delta)}{g_{t,k}}\right)\right) \tag{4.4}$$

where $g_{t,k} = \frac{K_k}{K_{k-1}}$ denotes the quarterly growth rate of capital in year t. For data observed at

[7] The pattern of capital expenditure reported in the Annual Capital Expenditure Survey from the US Census Bureau also shows that in contrast to large firms, small firms (classified by number of employees) invest more in structures compared to equipment. Over the period reported (1995-2006) small firms have an average ratio of structures to equipment expenditure equal to 0.60, while large firms have an average ratio equal to 0.49. The data are for the non farm business sector and cover the period 1995 to 2006. The Annual Capital Expenditure Survey reports capital expenditure separately by structures and equipment for firms with and without employees. The data can be found at: http://www.census.gov/csd/ace.

the annual frequency one can approximate the RHS of the above expression with

$$\frac{I^a_{t-1}}{K^a_t} - 4\varphi_1(1 - \frac{4(1-\delta)}{g^a_t}) \tag{4.5}$$

where the superscript a denotes annual measures. The expression above involves only observable variables, namely lagged investment rate adjusted by the growth rate of capital, $\frac{I^a_{t-1}}{K^a_t}$ and the growth rate of capital, g^a_t. It follows from the expression above that one need only use $\frac{I^a_{t-1}}{K^a_t}$ and the inverse growth rate of capital $(g^a_t)^{-1}$ as additional RHS regressors in the investment-q regression (the rest of the terms will be subsumed in the constant) to control for the omitted state variable. Most importantly the use of the variables above as RHS regressors has a very practical advantage from an empirical perspective; they do not require knowledge of the TTB length (i.e. the same regressors control for TTB for any J) or the TTB parameters.

4.4.1 Simulation analysis

Table 6 reports investment-q regression results augmented with the two variables above, i.e. lagged investment rate, and the inverse growth rate of capital. To judge the adequacy of our proposed controls for TTB we compare Table 6 with the regression results from Table 3. There are two notable findings. First, and most importantly the profit rate coefficient in Table 6 falls dramatically for all J as compared to the corresponding coefficients from Table 3 (see bottom panel, Table 6). For example, for $J = 3$ the profit rate coefficient drops to 0.004 compared to 0.29. The coefficient on the profit rate is still positive—due to the time aggregation error—but the adjusted R^2 does not increase when the profit rate is added to the regression indicating that this variable contains no explanatory power—as seen by the difference in the adjusted R^2 between the top and bottom panels of Table 6. Second, the TTB state variable can potentially account for a significant fraction of the total variance in the investment rate. This fraction can be calculated by comparing the R^2 values between Tables 3 and 10 which suggests that up to an additional 11% (for $J = 4$) of the total variance in investment can be explained by this channel. These results clearly suggest that the inclusion of the two proposed variables can sufficiently control for TTB investment and are therefore useful in empirical work.[8]

Another serious concern that often arises in empirical work with investment equations is the use of Tobin's or average q calculated from financial market data. Typically researchers are either unable to observe marginal q or the homogeneity assumptions that must be satisfied for the two measures to be equivalent are violated (due to for example market power or decreasing returns to scale). Thus researchers must rely on financial market information and use average (or Tobin's) q to control for future investment opportunities in the RHS of the investment regression. The use of average q has been criticized extensively because of the measurement error it may entail (see Erickson and Whited (2000) and Cummins et al. (2006) among others) but we think it is instructive to assess the regression implications when one has only available this imperfect measure. We introduce measurement error in our marginal q and use this noisy indicator as our q measure,

$$\overline{q_t^a} = q_t^a + \chi_t, \quad \chi_t \sim N(0, \sigma_\chi^2)$$

where χ denotes measurement error and we set σ_χ^2 to 1/10 the variance of marginal q^a implying a signal to noise ratio of 10. We report the results from regressing the investment rate on this noisy measure of q and the profit rate in Table 7. The estimated profit rate coefficients are noticeably larger compared to the corresponding coefficients from Table 3. For example, for $J = 3$ the estimated profit rate coefficient equals 0.42 compared to 0.29 in Table 3. These results suggest that the use of a noisy indicator of marginal q magnifies the specification error arising from TTB investment. Panel II of the same Table reports results when we control for TTB by including the additional RHS regressors and panel III adds the profit rate to the regression of panel II. The important finding from comparing panels II and III is that the role of profit rate is un-important as seen by the nil difference between the adjusted R^2 values at the bottom of Table 7. This

[8]In additional simulated regressions (not reported for brevity) we further examine the usefulness of these variables under the three alternative TTB parametrizations we examine in section 4.5. We note that the findings are qualitatively similar, namely, the coefficient of the profit rate approaches zero and adding the latter as an additional RHS regressor does not improve the predictive power of the regression.

demonstrates that the inclusion of the two variables that control for TTB investment is also robust to measurement error in q.

4.5 Robustness to TTB technology

In this section we consider three alternative calibrations of the TTB process using available evidence from various countries and manufacturing industries. First, there exists evidence indicating little resources are spent in the initial stages of the project (TTP spending pattern). For example, TTP effects seem to be an important feature for investment in structures (see Del Boca et al. (2008) and Koeva (2001), Christiano and Todd (1996) or Edge (2007)). Second, evidence indicating that spending follows a hump shaped pattern, i.e increasing when approaching the middle of the construction phase and declining towards the end (hump shaped TTB spending pattern, see Zhou (2000) and Palm et al. (1993)). Finally, evidence indicating that the majority of resources are spend in the first stages with a declining portion allocated in the later stages (declining TTB spending pattern, see Peeters (1998) and Altug (1989)). We explore these three different TTB spending patterns that imply time-to-plan (TTP) effects, hump shaped spending effects, and declining spending effects. Table 8 conveniently summarizes the TTB parameter values we use in each case. We re-estimate the investment equation (4.2) on our artificial panel using the three alternative parametrizations. Table 9 reports results under the TTP investment pattern. The regression results are qualitatively very similar to those in Table 3. The most notable finding from the TTP technology is that the role of the profit rate seems to be more important compared to the baseline TTB case. From Tables 3 and 9 we see that the estimated profit coefficients (b_2) are on average larger under TTP for all J, and that the predictive role of the profit rate (as captured by differences in the adjusted R^2) is higher. We also note that this result is consistent with the cross sectional implications we highlighted in the previous section. Given the evidence presented in section 4.2 we would expect small firms investment technology to have a stronger TTP element compared to large firms since the former invest dis-proportionately more in structures compared to the latter. Under TTP investment we would therefore expect differences in cash flow effects to be even more pronounced among firms that differ in size. Tables 10 and 11 report results for the hump shaped and declining pattern of TTB respectively. Tables 10 and 11, similar to Tables 3 and 7, show positive and statistically significant profit rate coefficients, validating the TTB channel for the emergence of the cash flow effect in these alternative parametrizations.

4.6 Empirical application

In this section we test the predictions of the theoretical model using firm level data from the UK manufacturing sector. This dataset consist of UK quoted company balance sheets collected by Datastream. The main variables we use are flows of investment, sales, profits, cash flow and Tobin's q. Investment is defined as the purchase of fixed assets by the firm. Cash flow is measured as the sum of the firm's after tax profits and depreciation. Tobin's q is computed as the ratio of the sum of the market value of the firm and the firm's total debt to the replacement value of its capital stock. The measure of the replacement value of capital stock is obtained from the book value of the firm's stock of net fixed assets, using the investment data in a standard perpetual inventory formula. The detailed data Appendix provides precise definitions and sources of all variables used in the empirical analysis. Table 12 reports summary statistics for the variables used in the empirical application. The first column lists the variables used. The second column reports sample means and standard deviations for all firm-years. The third and fourth columns reports the same information according to the size (based on the number of employees) classification.

The firm level panel we use comprises of 7091 firm-year observations (760 firms). As in previous work with the investment-q framework we estimate regressions with Tobin's q augmented by cash flow to illustrate the effect of the latter and the cross sectional sensitivity between different types of firms emphasized in the literature. We specify and estimate the identical equation we have used in the previous sections. In order to create sub-samples of firms that are expected to face different degrees of capital market imperfections we use size and dividend payout ratios as splitting criteria.

These classification criteria have been widely employed in previous work that test the capital markets imperfection hypothesis with the investment-q framework. For the size classification we use the number of employees (or alternatively real sales). We then further augment our equations with the two variables that aim to control for the omitted state variable as explained in section 4.4. The estimation results for the employment classification are presented in Table 13. We report both OLS (in columns (0) to (3)) and first differenced GMM (in columns (4) and (5)) results.[9] Columns (1) and (4) clearly demonstrate a cash flow effect present in the investment regression. The estimated cash flow coefficients are positive and significant in most cases at the 1% level. For example, the estimated cash flow coefficients in columns (1) and (4) range from 0.07 to 0.098 for small firms and 0.06 to 0.036 for large firms. Moreover, the difference in the cash flow coefficients between small and large firms based on the GMM estimates is significant at the 5% level as can be seen by the test on the equality of coefficients. These results are in line with typical findings reported in earlier work with UK firm level panel data (see e.g. Carpenter and Guariglia (2008), and Bond et al. (2003)). Despite the cash flow effect the tests on the GMM equations indicates some problems with this specification. The m_2 test of second order serial correlation of the first differenced residuals is rejected at the 10% level and while the Hansen's J test of overidentifying restrictions cannot be rejected at the 10% level, this is only marginal (see column (4)).

In columns (2), (3) and (5) we augment the regressions with the two variables that aim to control for any possible TTB effects. According to the simulated results of section 4.4, if the TTB channel is important, we would expect to see these variables to be statistically significant and improve the fit of the regression. First, as we can see from columns (2), (3) and (5) both of these variables enter the equations significantly; in all cases they are significant at the 1% level. In the GMM equation (column 5) both m_2 and Hansen' J test indicate no problems with the specification, whereas this inclusion improves the fit of the equation as seen by the adjusted R^2 values in columns

[9]We present results using both methods, we note however, that the most recent empirical literature typically reports results from first-differenced GMM specifications.

(2) and (3). More importantly, the cash flow effect almost completely disappears as can be seen by the estimated coefficients for both types of firms—small and large. The estimated coefficients for small and large firms decline from 0.098 to 0.014 and from 0.036 to 0.012 respectively (comparing columns (4) and (5)) and we cannot reject the null of equality between them. Looking across the OLS estimates we note that the explanatory power of the regression when the two variables are included as RHS regressors is improving significantly. For example the adjusted R^2 rises from 0.21 (when only Tobin's q is included) to 0.60 when the two additional variables are included (compare columns (0) and (3)). Further, adding cash flow to this last regression only marginally improves the fit of the equation from 0.60 to 0.61 (compare columns (2) and (3)) and the size of the coefficients are significantly smaller. Thus the inclusion of the two variables that aim to control for the TTB effect of investment nearly eliminate the cash flow effect previously estimated. A similar set of findings is reported in Tables 14 and 15 when alternative classification schemes are used. Last, we note that the coefficient on q appears to be quite small and implies large adjustment cost estimates. We remind the readers that the coefficient on q would also reflect the TTB parameters and hence the true adjustment cost estimate may be much larger than the one implied here. Although it is not possible to separately identify the TTB from the adjustment cost parameter in this framework, a suggestive back of the envelope calculation using the calibrated TTB parameters shows that the coefficients on Tobin's q should be scaled by a factor of between 4 to 10 (corresponding to $\varphi_J = 0.25$ and $\varphi_J = 0.1$) implying much lower adjustment cost estimates. However, an additional confounding factor that makes the interpretation of q problematic is the likely measurement error present in Tobin's q. Controlling for the latter as in Erickson and Whited (2000) may also resolve part of the bias present in the Tobin's q coefficient.

The results from the empirical analysis are remarkably in line with the predictions of the theoretical model; the TTB channel emphasized in this study appears to be able to explain away the cash flow effect, a very robust finding in the empirical investment-q literature. These findings therefore pose a question mark on the validity of the interpretation of the cash flow effect in the investment-q framework.

5 Conclusions

We revisit the interpretation of an important empirical regularity, namely the finding, established in a large body of empirical work, that cash flow is important in investment regressions because it reflects capital market imperfections. This paper develops a rich decision theoretic model of investment with time-to-build and time-to-plan features for the installation of capital and shows that cash flow may be found to be important even if capital markets are perfect and even when future investment opportunities are properly accounted for. This new explanation relies on the idea and supportive empirical evidence that it takes time to build productive capital. With time-to-build, the simple q framework is inadequate to fully explain optimal investment as it omits a key state variable from the investment regression. We show how a researcher can, under certain assumptions on the time-to-build technology, approximate for this omitted state variable and hence obtain the correct inference from a modified investment-q regression. We evaluate the validity of the TTB channel in a large panel of UK manufacturing firms and find that the cash flow effect largely disappears when we control for TTB investment confirming the predictions of the model. Our results suggest that investment cash flow sensitivities are not the right framework to evaluate the capital market imperfections view. Recently, researchers have undertaken carefully designed tests that are robust to a range of problems associated with this framework. Rauh (2006) for example designs an experiment that can identify variation in the availability of internal funds that is by construction orthogonal to future investment opportunities. His results lend support to the existence of capital market imperfections. Another type of capital that should be less subject to the critique raised in this paper is inventories. Inventories are most likely not subject to TTB effects and have low adjustment costs compared to fixed investment suggesting they provide a more robust way to test for the perfect capital markets hypothesis.

Finally, since our model is designed with perfect capital markets, is not equipped to evaluate the impact of capital market imperfections in the investment-q regressions we have examined. It is entirely possible that at least some of the cash flow effects found in previous empirical work are due to agency costs in capital markets that drive a wedge between the cost of internal and external finance. We can only conjecture that if capital market imperfections coexist with TTB effects will render cash flow sensitivities difficult to interpret as indicators for the severity of financing constraints. An interesting possibility is to examine how the presence of capital market imperfections can interact and influence the length of TTB. One may reasonably conjecture that small firms may be characterized by lengthier TTB technology because they are constrained in the funds they can extract from the market in order to proceed with the construction (or delivery) stages of their projects. This is an interesting avenue left for future research.

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A Appendix 1

This section derives the equilibrium conditions of the model. A firm i in this industry solves (dropping the subscript):

$$\max_{L_t, s_{Jt}, d_t} E_0 \sum_{t=0}^{\infty} \beta^t div_t \tag{A.1}$$

$s.t.$

$$div_t = A_t \omega_t K_t^{\alpha} M_t^{\gamma} L_t^{\nu} - wL_t - d_t - I_t - \frac{\eta}{2}(\frac{s_{Jt}}{K_t} - \delta)^2 K_t$$

$$K_{t+1} = (1-\delta)K_t + s_{1t}$$

$$s_{Jt} = s_{J-1,t+1}$$

$$I_t = \sum_{i=1}^{J} \varphi_i s_{it}$$

with $0 \leq \varphi_i \leq 1, \quad i = 1, 2, ...J,$

$$M_{t+1} = (1-\delta_m)M_t + d_t$$

$$lnA_{t+1} = \rho_A lnA_t + \sigma_A \varepsilon_{t+1}^A \quad \varepsilon_t^A \sim N(0,1)$$

$$ln\omega_{t+1} = \rho_\omega ln\omega_t + \sigma_\omega \varepsilon_{t+1}^\omega \quad \varepsilon_t^\omega \sim N(0,1)$$

given the initial values, K_0, M_0, s_{j0}, $j = 1, ..., J-1$; $\{\varepsilon_t^A\}_{t=-J+1}^0$, $\{\varepsilon_t^\omega\}_{t=-J+1}^0$.

Introducing the Kuhn-Tucker multipliers q_t and μ_t we can write the Langrangean for this problem,

$$\max_{L_t, s_{Jt}, d_t} E_0 \sum_{t=0}^{\infty} \beta^t \{div_t + q_t(K_{t+1} - (1-\delta)K_t - s_{1t}) + \mu_t(M_{t+1} - (1-\delta_m)M_t - d_t)\}$$

The first order conditions associated with this problem are:

w.r.t L_t (labor)

$$(\nu A_t \omega_t K_t^{\alpha} M_t^{\gamma} L_t^{\nu-1} - w) = 0$$

w.r.t d_t (deliveries)

$$-1 + \beta E_t \left\{ A_{t+1}\omega_{t+1}\gamma K_{t+1}^{\alpha} M_{t+1}^{\gamma-1} L_{t+1}^{\nu} + (1-\delta_m) \right\} = 0$$

w.r.t s_{Jt} (project starts)

$$-\beta^t(\varphi_J + \eta(\frac{s_{Jt}}{K_t} - \delta)) - \beta^{t+1}E_t(\varphi_{J-1}) - \beta^{t+2}E_t(\varphi_{J-2})$$

$$+ ... + \beta^{t+J-1}E_t(-\varphi_1 + q_{t+J-1}) = 0$$

w.r.t K_{t+J} (capital)

$$\beta^{t+J-1}E_t(-q_{t+J-1})$$

$$+\beta^{t+J}E_t\left\{ A_{t+J}\omega_{t+J}\alpha K_{t+J}^{\alpha-1} M_{t+J}^{\gamma} L_{t+J}^{\nu} + \eta(\frac{s_{J,t+J}}{K_{t+J}} - \delta)\frac{s_{J,t+J}}{K_{t+J}} - \frac{\eta}{2}(\frac{s_{J,t+J}}{K_{t+J}} - \delta)^2 + q_{t+J}(1-\delta) \right\} = 0$$

$$q_t(K_{t+1} - (1-\delta)K_t - s_{1t}) = 0 \quad q_t \geq 0$$

$$\mu_t(M_{t+1} - (1-\delta_m)M_t - d_t) = 0 \quad \mu_t \geq 0$$

Collecting all the equations above that characterize equilibrium yields:

$$E_t F(y_{t+J}, ..., y_{t+1}, y_t, x_{t+J}, ..., x_{t+1}, x_t) = 0 \tag{A.2}$$

where E_t denotes the mathematical expectations operator conditional on information at time t, x_t denotes the vector of state variables and consists of capital, K_t, materials, M_t partially complete projects, $\{s_{jt}\}_{j=1}^{J-1}$, and the two exogenous precesses for productivity, A_t, and ω_t. The vector y_t denotes the vector of choice variables and consists of labor, L_t, materials orders, d_t, and new projects, s_{Jt}. The solution to the model given in equation $A.2$ can be expressed as

$$y_t = g(x_t, \sigma)$$

$$x_{t+1} = h(x_t, \sigma) + \pi\sigma\varepsilon_{t+1}$$

where g is a function that maps the vector of states, x_t to choice variables, y_t, h is a function that maps the state vector at time t to time $t+1$, π is a vector selecting the exogenous state variables, in this case A_t and ω_t, and $\sigma = [\sigma_A \, \sigma_\omega]$. We want to find a second order approximation of the functions, g, h around the non-stochastic steady state, $(x_t, \sigma) = (\overline{x}, 0)$. The non-stochastic steady state is defined as vectors $(\overline{x}, \overline{y})$ such that $F(\overline{y}, ..., \overline{y}, \overline{y}, \overline{x}, ..., \overline{x}, \overline{x}) = 0$.

To compute the second order approximation around $(x, \sigma) = (\overline{x}, 0)$, one substitutes the proposed policy rules into (A.2) and makes use of the fact that derivatives of any order of (A.2) must equal zero in order to compute the coefficients of the Taylor approximations of the proposed policy functions. The second order solution for all variables of the model is completely characterized by the matrices that collect the first and second order derivatives of the policy (g) and transition (h) functions with respect to the state variables and σ, $g_x, h_x, g_{xx}, h_{xx}, g_{\sigma\sigma}, h_{\sigma\sigma}$. For example, the second order approximation for g and h can be written respectively as (see Schmitt-Grohe and Uribe (2004)),

$$[g(x,\sigma)]^i = [g(\overline{x},0)]^i + [g_x(\overline{x},0)]^i_a (x-\overline{x})_a + \frac{1}{2}[g_{xx}(\overline{x},0)]^i_{ab}(x-\overline{x})_a(x-\overline{x})_b + \frac{1}{2}[g_{\sigma\sigma}(\overline{x},0)]^i[\sigma][\sigma]$$

$$[h(x,\sigma)]^j = [h(\overline{x},0)]^j + [h_x(\overline{x},0)]^j_a (x-\overline{x})_a + \frac{1}{2}[h_{xx}(\overline{x},0)]^j_{ab}(x-\overline{x})_a(x-\overline{x})_b + \frac{1}{2}[g_{\sigma\sigma}(\overline{x},0)]^j[\sigma][\sigma]$$

where $i = L, s_J, d,\ a, b = K, M, \{s_j\}_{j=1}^{J-1}, A, \omega,\ j = K, M, \{s_j\}_{j=1}^{J-1}, A, \omega$. $[g_x]_a^i, [h_x]_a^i$ denote the (i, a) element of the first order derivative of g, h with respect to x and similarly for the second order derivatives. Notice that all the matrices collecting first and second order derivatives above are evaluated at the non-stochastic steady state, i.e. $(\overline{x}, 0)$. In turn the non-stochastic steady state can be easily computed by solving the f.o.c's setting $A_t = A_{t+1} = E(A)$ and similarly $\omega_t = \omega_{t+1} = E(\omega)$ and solving the resulting static system of equations for $\overline{x}, \overline{y}$.

B Appendix 2

Description of the calibration. The values for the output elasticity of materials, γ, labor, ν and capital, α are taken from the manufacturing plant level study of Sakellaris and Wilson (2004) (Table 1, p.15, C). These values imply an overall returns to scale equal to 0.98. This value is consistent with Basu and Fernald (1997) estimates of the returns to scale in manufacturing. There is a variety of empirical evidence of time-to-build for capital projects. Regarding equipment investment, Abel and Blanchard (1986) document an average delivery lag for manufacturing firms equal to three quarters (during which time they pay installments for the purchase of the capital good). Mayer and Sonenblum (1955) report that the average time across industries needed to equip plants with new machinery is 2.7 quarters. Montgomery (1995) examines a long series of finely detailed surveys conducted by the U.S. Department of Commerce on TTB patterns for a wide range of firm construction projects. His calculations imply a time-to-build between five to six quarter for non-residential structures. There is still evidence of lengthier construction times for non-residential structures. According to Mayer (1960) and Koeva (2001) it takes approximately two years to complete non-residential structures. A recent study by Del Boca et al. (2008) using Italian firm level data suggests that investment projects require 2-3 years from initial stage to completion, while equipment investment becomes productive within a year. Based on this evidence and given the fact that the model's empirical counterpart is total capital we think that three or four quarters is a reasonable length for the time-to-build assumption. We set the length of the time-to-build equal to three quarters (J=3) in our baseline calibration but we also discuss results varying this value up to four quarters. In terms of the resources spent on each stage of the construction (or installments for delivery) Kydland and Prescott (1982) assume an equal cost distribution. Recently, Zhou (2000) argues that time-to-build is very important for explaining investment dynamics. He estimates φ_i for various values of J and reports that an (approximately) equal distribution of cost for time-to-build investment produces the best fit for aggregate U.S. investment. There also exist estimates (e.g. Del Boca et al. (2008)) particularly for investment in structures that point to initial planning phases with little or no resources spent followed by construction phases with increasing resources as projects near completion. This pattern of spending is known as time-to-plan (TTP). For the baseline calibration we set $\varphi_1 = \varphi_3 = 0.333, \varphi_2 = 0.34$ and explore TTP in the simulations as an alternative scenario. The parameter that governs the convexity of the adjustment cost function, η is set equal to 1.08 at the quarterly rate. This parameter is estimated by Barnett and Sakellaris (1999) using a Tobin's q approach in a panel of manufacturing firms from 1959 to 1987 (see Table 3 p.256). In implementing their approach the authors assume a time-to-build of one year thus closely corresponding to our assumptions. The magnitude of (convex) adjustment costs estimated by Barnett and Sakellaris (1999) and more recently by Cooper and Haltiwanger (2006) seem to be conforming much better to the q theory of investment compared to earlier estimates that produced implausibly large adjustment cost estimates (See for example, Hayashi (1982), or Summers (1981)).We choose to work with these recent (more realistic) estimates for another reason. A higher adjustment cost parameter η would imply a greater positive serial correlation of investment that would (in the presence of autocorrelated productivity) be more strongly correlated with profits, thus making it easier to obtain a significant profit rate coefficient in a mis-specified regression. We also experiment with several alternative values for η taken from these studies. The subjective discount factor, β, is chosen to match the average risk-free real interest rate over the period 1947 I to 2006 II. The real interest rate is defined as the 3-month U.S. T-bill rate less consumer price inflation. The depreciation rate for materials is calculated as follows. The stock of materials at the end of a quarter is $(1-\delta_m)M_t$. Usage of materials in quarter t is $\delta_m M_t$. Since usage is not available quarterly but only annually we use the following approximation. $usage_q^y = \frac{usage^y}{output^y} output_q^y$, where y denotes year and q quarters. This calculation should be sufficiently accurate since materials usage and output are highly correlated and their ratio will thus be quite smooth in the short-run. The data used for this calculation are available from the Annual Survey of Manufacturers (ASM) and the NBER manufacturing productivity database. δ_m is then calculated from the restriction $\frac{(1-\delta_m)M_t}{\delta_m M_t} = \frac{\text{materials inventories at end quarter t}}{\text{usage of materials in quarter t}}$. In the data (1962-2000) the ratio is on average equal to 0.33. The calculation implies $\delta_m = 0.75$. We set δ the fixed capital depreciation rate to 0.025 per quarter. We calibrate the process for the idiosyncratic productivity shock, ρ_ω, σ_ω to match the autocorrelation and standard deviation of (cyclical) aggregate manufacturing investment. Finally, we calibrate the process for the aggregate productivity shock, ρ_A, σ_A to match the autocorrelation and standard deviation of (cyclical) aggregate manufacturing output. The data for this calculation (manufacturing investment and output) are taken from the Bureau of Economic Analysis and cover the period 1967 II to 2004 IV.

C Appendix 3

Time Aggregation. To obtain annual from quarterly measures we adopt the same methodology as in the national accounts and employed by Hall (2004). Specifically, we set all the *flow* variables at the annual rate equal to the sum of the corresponding *flow* variables over the quarters, i.e., for *flow* variable x, $x_t^a = \sum_{k=1}^4 x_{t,k}$, where $x = I, \pi, s_i, \, , i = 1, ...J$ and a denotes annual frequency.

The annual measure for marginal q, is the average over the corresponding quarterly measure. However, it differs slightly depending on the TTB. We use the following definitions,

$$J = 1\,, q_t^a = \frac{\sum_{k=1}^4 q_{t,k}}{4} \quad J = 2\,, q_t^a = \frac{\sum_{k=1}^4 E_k q_{t,k+1}}{4}$$

$$J = 3\,, q_t^a = \frac{\sum_{k=1}^{4} E_k q_{t,k+2}}{4} \quad J = 4\,, q_t^a = \frac{\sum_{k=1}^{4} E_k q_{t,k+3}}{4}$$

In general $\frac{\sum_{k=1}^{4} E_k q_{t,k+J-1}}{4} \neq \frac{\sum_{k=1}^{4} q_{t,k}}{4}$. However, with autocorrelated productivity shocks the two measures are highly correlated. We use the marginal expected q for each different J to isolate the omitted variable effect. Our results are broadly similar if we use the same q for each J. Finally, we take the annual capital stock to correspond to the end of year (i.e. fourth quarter) stock. Alternatively, the annual measure for the capital stock can be calculated from $K_{t+1}^a = (1-\delta^a)K_t^a + s_{1t}^a$. The results are insensitive to this alternative definition.

Expression for the time aggregation error. To derive this expression we assume no TTB (i.e. $J = 1$). We begin with equation,

$$-4 - \eta\Bigg(\sum_{k=1}^{4}(\frac{I_{t,k}}{K_{t,k}} - \delta)\Bigg) + \sum_{k=1}^{4} q_{t,k} = 0$$

where t denotes years.

If we add and subtract $\eta\Bigg(\sum_{k=1}^{4}(\frac{I_{t,k}}{K_t^a} - \delta)\Bigg)$ we get

$$-4 - \eta\Bigg(\sum_{k=1}^{4}(\frac{I_{t,k}}{K_t^a} - \delta)\Bigg) + \eta\Bigg(\frac{1}{K_t^a}\sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}\Bigg) + \sum_{k=1}^{4} q_{t,k} = 0$$

The term, $\Bigg(\frac{1}{K_t^a}\sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}\Bigg)$ which will be $\neq 0$ in general, represents the time aggregation error. It is easy to see that this term will be zero only when investment is equal to replacement investment (δK), so that capital in year t, $K_t^a = K_{t,k}$. Similar expressions for the time aggregation error characterize $J = 2, 3, 4$.

Re-writing this equation (dividing by four and using $\sum_{k=1}^{4}\frac{I_{t,k}}{K_t^a} = \frac{I_t^a}{K_t^a}$, $q_t^a = \frac{\sum_{k=1}^{4} q_{t,k}}{4}$,$\frac{1}{\frac{\eta}{4}} = \frac{1}{\eta^a}$) after suppressing all the constant terms yields the final equation,

$$\frac{I_t^a}{K_t^a} = constant + \Bigg(\frac{1}{K_t^a}\sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}K_{t,k} - \sum_{k=1}^{4}\frac{I_{t,k}}{K_{t,k}}\Bigg) + \frac{1}{\eta^a}q_t^a$$

Empirical proxy. Next, we show the derivation of the empirical proxy in equation 4.5.

$$\sum_{k=1}^{4}\frac{\sum_{i=1}^{2}\varphi_i s_{it,k}}{K_{t,k}}=\sum_{k=1}^{4}(\frac{I_{t-1,k}}{K_{t,k}}-\varphi_1(1-\frac{(1-\delta)}{g_{t,k}})+\varphi_1(\frac{\varphi_2}{\varphi_1}-1)\frac{s_{1t,k}}{K_{t,k}}+\varphi_2(\frac{\varphi_3}{\varphi_2}-1)\frac{s_{2t,k}}{K_{t,k}})$$

The RHS of the equation above yields,

$$\frac{I^a_{t-1}}{K^a_t}+\sum_{k=1}^{4}(\frac{I_{t-1,k}}{K_{t,k}}-\frac{I_{t-1,k}}{K^a_t})-\varphi_1\sum_{k=1}^{4}\big(1-\frac{(1-\delta)}{g_{t,k}})\big)+\big(\varphi_1(\frac{\varphi_2}{\varphi_1}-1)\frac{s_{1t,k}}{K_{t,k}}+\varphi_2(\frac{\varphi_3}{\varphi_2}-1)\frac{s_{2t,k}}{K_{t,k}})$$

Equation 4.7 in the text follows from the above when we impose the symmetry assumption of TTB (i.e. $\varphi_1=\varphi_2=\varphi_3$) and use $g_{t,k}\approxeq\frac{1}{4}g^a_t$.

Coefficient bias. We derive the expressions that determine the biases in the coefficients of q and the profit rate in the investment regression.

Consider the regression

$$y=X_1\beta_1+X_2\beta_2+X_3\beta_3+u$$

where $y=\frac{I^a_t}{K^a_t}, X_1=q^a_t, X_2=\frac{\pi^a_t}{K^a_t}, X_3=\sum_{k=1}^{4}\frac{\sum_{i=1}^{2}\varphi_i s_{it,k}}{K_{t,k}}$. The true coefficient of $\frac{\pi^a_t}{K^a_t}$ will be $\beta_2=0$. Now suppose we specify the following regression equation (i.e. equation 4.4)

$$y=X_1\beta_1+X_2\beta_2+e$$

where the error e term is now given by

$$e=X_3\beta_3+u$$

The OLS coefficient vector is given by,

$$\begin{bmatrix}b_1\\b_2\end{bmatrix}=\begin{bmatrix}X_1'X_1 & X_1'X_2\\X_2'X_1 & X_2'X_2\end{bmatrix}\begin{bmatrix}X_1'y\\X_2'y\end{bmatrix}$$

Using standard matrix formulas this equation can be written as,

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} D_1^{-1} & D_2^{-1} \\ D_3^{-1} & D_4^{-1} \end{bmatrix} \begin{bmatrix} X_1'y \\ X_2'y \end{bmatrix}$$

where $D_1^{-1} = (X_1'X_1 - X_1'X_2(X_2'X_2)^{-1}X_2'X_1)^{-1}$,

$D_2^{-1} = -(X_1'X_1 - X_1'X_2(X_2'X_2)^{-1}X_2'X_1)^{-1}(X_1'X_2)(X_2'X_2)^{-1}$,

$D_3^{-1} = -(X_2'X_2)^{-1}(X_2'X_1)(X_1'X_1 - X_1'X_2(X_2'X_2)^{-1}X_2'X_1)^{-1}$,

$D_4^{-1} = (X_2'X_2)^{-1} + (X_2'X_2)^{-1}(X_2'X_1)(X_1'X_1 - X_1'X_2(X_2'X_2)^{-1}X_2'X_1)^{-1}(X_1'X_2)(X_2'X_2)^{-1}$

The expected value of the OLS coefficients on the profit rate and marginal q will be given by,

$$E(b_2) = [D_3^{-1}(X_1'X_1) + D_4^{-1}(X_2'X_1)]\beta_1 + [D_3^{-1}(X_1'X_3) + D_4^{-1}(X_2'X_3)]\beta_3$$

$$E(b_1) = [D_1^{-1}(X_1'X_1) + D_2^{-1}(X_2'X_1)]\beta_1 + [D_1^{-1}(X_1'X_3) + D_2^{-1}(X_2'X_3)]\beta_3$$

One can show that $D_1^{-1} > 0, D_2^{-1} < 0, D_3^{-1} < 0, D_4^{-1} > 0$ as long as $(X_1'X_1 - X_1'X_2(X_2'X_2)^{-1}X_2'X_1)^{-1} > 0$. Since $X_1 = q_t^a, X_2 = \frac{\pi_t^a}{K_t^a}$ this condition simplifies to $(var(q_t^a) - cov(q_t^a, \frac{\pi_t^a}{K_t^a})var(\frac{\pi_t^a}{K_t^a})^{-1}cov(q_t^a, \frac{\pi_t^a}{K_t^a})) > 0$. This can further be written as $1 > \rho_{x_1,x_2}^2$ which will be always satisfied unless $\rho_{x_1,x_2}^2 = 1$. It is easy to see from the expressions above that when this condition is satisfied, $E(b_2)$ will fall with β_1, while $E(b_1)$ will rise with β_1 and rise with β_3. Therefore as long as φ_J is falling with J this will always be the case.

D Data Appendix

We started with 11,536 firm-year observations (1113 firms) over the period 1980-2000. We excluded firms that changed the date of their accounting year-end by more than a few weeks, so that the data refers to 12 month accounting periods. To control for the potential influence of outliers we removed observations beyond the 1st and 99th percentiles for each of the regression variables; we also excluded observations characterized by an investment to capital ratio greater than one. This trimming is aimed at eliminating observations reflecting particularly large mergers or coding errors. Note that these types of sample selection are common in the literature and we employ them for compatibility with previous work. We have also dropped firm-year observations that did not have complete records on the variables used in our regressions. Moreover, because we use Generalized Method of Moments (GMM) to estimate the investment equations in first differences with values of the regressors lagged twice or more as instruments we require at least three cross sectional observations to allow for the first differencing process and the construction of the instruments. This meant that only firms with a minimum of three consecutive observations were kept in the sample. After all these adjustments we were left with a panel of 7091 firm-year observations (760 firms). The following describes the construction of variables (with Datastream codes in parenthesis where applicable).

Investment(I). Up to 1991: fixed assets purchased by the company excluding assets acquired from new subsidiaries (v341). After 1991: cash paid by the company towards the purchase of fixed assets (v1024: property, plant or equipment).

Depreciation(δ). We use rates of 8.19% for plant and machinery and 2.5% for land and buildings (from King and Fullerton (1984)). For each observation we then calculate the proportion of land and building investment and calculate the depreciation rate as follows: $\delta = 0.0819*(1-mb)+0.025*mb$, where mb is the average value of the proportion of buildings investment as described above.

Replacement value of the capital stock(K). We use net tangible fixed assets as the historic value of the capital stock (as computed above). We assume that replacement cost and historic cost are the same in the first year of data for each firm. We then apply the perpetual inventory formula (Bond and Meghir (1994)) as follows: $K_t = K_{t-1} * (1-\delta) * \frac{P_t}{P_{t-1}} + I_t$. In the formula P_t denotes the price of investment goods computed from the implicit deflator for gross fixed capital formation available from the National Statistics Office.

Cash flow(CF). Sum of after tax profits (v623) and depreciation (v136).

Tobin's q (q). Ratio of value of firm to replacement value of capital. Value of firm is the sum of enterprise value of firm (v1504), borrowings repayable within one year (v309), total loan capital repayable after one year (v321).

Total number of employees. Average number of employees as disclosed by the company (v219).

Sales. Amount of goods and services to third parties relating to the normal industrial activities of the company (v104). Real sales are obtained by dividing with the GDP deflator.

Dividend payout ratio. Ratio of dividends (v187) to operating profits (v137).

The two variables that proxy for the omitted state variable due to TTB investment as constructed as follows.

$\frac{I_{t-1}}{K_t}$: using the definitions of investment and capital provided above.

Inverse of the gross growth rate of capital. $(g^k)^{-1} = \frac{k_{t-1}}{k_t}$, where k is capital as computed above (K) deflated by the GDP deflator.

E Appendix on inference and biases under TTB investment

In this section we report the inference problem in the investment-q framework under TTB investment. As explained in section 4.1.1 an investment-q regression that fails to account for TTB would lead one (a) to overestimate the adjustment cost parameter implied by the coefficient of q due to the scaling by the TTB parameter and (b) introduce a positive bias in the profit rate coefficient, as the true value of the latter in this model is equal to zero. In addition to this information we also report the *true bias* of the coefficient on q assuming that a researcher knows the true value of φ_J and adjusts the coefficient estimate of b_1 accordingly. Table 16 summarizes this information. Note that under all TTB parametrizations the inferred adjustment cost estimate, $\widehat{\eta^a}$ is always higher than the true value and rises with J. By contrast in the hypothetical case a researcher knows the TTB parameters the coefficient on q is biased upward (equivalently the adjustment cost estimate is biased downwards) and the true bias is negative. This is due to the fact that the mean value of the coefficient on q rises with the true parameter of the omitted state variable. Finally, the bias of the profit rate coefficient is always positive and rises with J.

Table 1: Calibrated parameters

	Description	Value	Source
γ	elasticity materials	0.53	Sakellaris and Wilson (2004) (Table 1, p.15, C)
ν	elasticity labor	0.32	Sakellaris and Wilson (2004) (Table 1, p.15, C)
α	elasticity capital	0.13	Sakellaris and Wilson (2004) (Table 1, p.15, C)
φ_1	fraction in final stage	0.33	various (see Appendix)
φ_2	fraction in middle stage	0.34	various (see Appendix)
φ_3	fraction in initial stage	0.33	various (see Appendix)
δ	depreciation capital	0.025	standard value from literature
δ_m	depreciation materials	0.75	NBER man. productivity data
$\beta = \frac{1}{1+r}$	discount factor	0.99	average risk free rate
η^a	adjustment cost	0.27	Barnett and Sakellaris (1999) estimates
σ_A	std. deviation common	0.045	BEA manufacturing output
ρ_A	AR(1) common	0.90	BEA manufacturing output
σ_ω	std. deviation idiosyncratic	0.025	BEA manufacturing investment
ρ_ω	AR(1) idiosyncratic	0.90	BEA manufacturing investment

Notes. See Appendix 2 for a detailed description of the calibration sources.

Table 2: Investment regressions–empirical specification

Coefficient	$J = 1$	$J = 2$	$J = 3$	$J = 4$
b_1	0.91	0.55	0.41	0.33
	(0.0001)	(0.001)	(0.002)	(0.002)
b_2	0.0001	0.49	0.54	0.58
	(0.0001)	(0.001)	(0.002)	(0.003)
$\overline{R}^2$	0.99	0.97	0.92	0.87

Notes. The Table reports coefficients of the regression, $\frac{I_{j,t}}{K_{j,t}} = \alpha + b_1 E_t(q_{j,t+2}) + b_2 \frac{\pi_{j,t}}{K_{j,t}} + \varepsilon_{j,t}$ based on the quarterly model. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 3: Investment regressions–empirical specification with annual measures

True $\eta^a = \mathit{0.27}$ Coefficient	$J=1$	$J=2$	$J=3$	$J=4$
b_1	3.50	3.37	3.20	3.00
	(0.0001)	(0.004)	(0.008)	(0.01)
$\widehat{\eta}^a = \frac{1}{b_1}$	*0.28*	*0.29*	*0.31*	*0.33*
$\overline{R}^2$	0.99	0.98	0.94	0.88
b_1	3.46	2.97	2.55	2.20
	(0.001)	(0.006)	(0.01)	(0.02)
b_2	0.03	0.22	0.29	0.35
	(0.0007)	(0.003)	(0.004)	(0.006)
$\overline{R}^2$	0.99	0.99	0.95	0.91

Notes. The top panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + \varepsilon_t^a$. The bottom panel reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 4: Correlations (baseline calibration)

State variable	$J=4$ $\sum_{k=1}^{4} \frac{\sum_{i=1}^{3} \varphi_i s_{it,k}}{K_{t,k}}$	$J=3$ $\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} \varphi_i s_{it,k}}{K_{t,k}}$	$J=2$ $\sum_{k=1}^{4} \frac{\sum_{i=1}^{1} \varphi_i s_{it,k}}{K_{t,k}}$	
$\frac{\pi_t^a}{K_t^a}$	0.73	0.85	0.84	
$J=3$				
	$\frac{I_t^a}{K_t^a}$	$\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} \varphi_i s_{it,k}}{K_{t,k}}$	$\frac{\pi_t^a}{K_t^a}$	q_t^a
$\frac{I_t^a}{K_t^a}$	1	0.99	0.86	0.97
$\sum_{k=1}^{4} \frac{\sum_{i=1}^{2} s_{it,k}}{K_{t,k}}$		1	0.85	0.93
$\frac{\pi_t^a}{K_t^a}$			1	0.83
q_t^a				1

Notes. This Table reports correlations between the profit rate and the state variable that arises under the TTB assumption. In this Table J denotes TTB in quarters. All statistics are averages over 500 replications.

Table 5: Firm level data–Evidence for TTB

Firm-year observations	Mean values	Size: Small	Size: Large	Test: $(\frac{I_{str}}{I_{eqp}})_{small} > (\frac{I_{str}}{I_{eqp}})_{large}$
I. Compustat (1980-2007)				
4818	$\frac{I_{str}}{I_{eqp}}$	$0.36^{\flat}$	0.29	$p-value$=0.042
7628	$\frac{I_{str}}{I_{eqp}}$	$0.37^{\dagger}$	0.32	$p-value$=0.095
II. Datastream (1980-2000)				
3885	$\frac{I_{str}}{I_{eqp}}$	$0.51^{\flat}$	0.24	$p-value$=0.19
3856	$\frac{I_{str}}{I_{eqp}}$	$0.48^{\dagger}$	0.18	$p-value$=0.18

Notes. Upper panel: Compustat sample of manufacturing firms. Lower panel: Datastream sample of manufacturing firms. Small firms are classified as belonging to the lower 25 percentile using either real sales ($^{\flat}$) or real total assets (†). Large firms are those belonging to the upper 25 percentile of the corresponding distribution. We use the method proposed by Bond and Meghir (1994) to estimate gross investment in structures (I_{str}) and equipment (I_{eqp}). Specifically we use the following calculation: $I_{it} = I_{Tt}\frac{\Delta K_{it}}{\Delta K_{Tt}}$, where i=structures, equipment. I_{Tt} denotes total gross investment (Compustat data item 30, Datastream item v431 and v1024), K_{it} capital stock (book value) in i=structures, equipment (Compustat data item 155 and 156, Datastream item v327 and v328) and K_{Tt} total (book value) capital stock (Compustat data item 8, Datastream item v330).

Table 6: Investment regressions–empirical specification with annual measures: controlling for TTB (baseline TTB)

Coefficient	$J=2$	$J=3$	$J=4$
b_1	2.23	1.79	1.31
	(0.001)	(0.003)	(0.005)
b_3	0.24	0.38	0.69
	(0.002)	(0.003)	(0.005)
b_4	-0.11	-0.11	0.03
	(0.004)	(0.003)	(0.004)
$\overline{R}^2$	0.99	0.99	0.99
b_1	2.21	1.78	1.23
	(0.001)	(0.001)	(0.01)
b_2	-0.02	0.004	0.04
	(0.004)	(0.004)	(0.006)
b_3	0.24	0.37	0.69
	(0.001)	(0.003)	(0.005)
b_4	-0.14	-0.12	0.05
	(0.002)	(0.003)	(0.004)
$\overline{R}^2$	0.99	0.99	0.99
$\Delta\overline{R}^2$ between top and bottom panels	0.00	0.00	0.00

Notes. Baseline TTB as calibrated in Table 8. The top panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_3 \frac{I_{t-1}^a}{K_t^a} + b_4 (g_t^a)^{-1} + \varepsilon_t^a$. The bottom panel reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + b_3 \frac{I_{t-1}^a}{K_t^a} + b_4 (g_t^a)^{-1} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 7: Investment regressions–empirical specification with annual measures **and measurement error in** q: TTB baseline pattern

Coefficient	$J = 2$	$J = 3$	$J = 4$
I.			
b_1	2.62	2.23	1.58
	(0.01)	(0.01)	(0.01)
b_2	0.40	0.42	0.44
	(0.008)	(0.005)	(0.006)
$\overline{R}^2$	0.96	0.93	0.89
II.			
b_1	1.05	1.22	0.92
	(0.008)	(0.008)	(0.007)
b_3	0.13	0.62	0.92
	(0.004)	(0.01)	(0.01)
b_4	-0.53	-0.03	0.15
	(0.004)	(0.01)	(0.01)
$\overline{R}^2$	0.98	0.98	0.98
III.			
b_1	0.99	1.06	0.59
	(0.005)	(0.005)	(0.02)
b_2	-0.13	0.17	0.14
	(0.008)	(0.009)	(0.007)
b_3	0.10	0.64	1.06
	(0.003)	(0.01)	(0.007)
b_4	-0.64	0.06	0.33
	(0.005)	(0.01)	(0.005)
$\overline{R}^2$	0.98	0.98	0.98
$\Delta\overline{R}^2$ between panels II and III	0.00	0.00	0.00

Notes. Baseline TTB pattern as calibrated in Table 8. Panel I reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$. Panel II reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_3 \frac{I_{t-1}^a}{K_t^a} + b_4 (g_t^a)^{-1} + \varepsilon_t^a$. Panel III reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + b_3 \frac{I_{t-1}^a}{K_t^a} + b_4 (g_t^a)^{-1} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 8: TTB parametrizations

		Baseline TTB pattern		
J = 2			$\varphi_2 = 0.5$	$\varphi_1 = 0.5$
J = 3		$\varphi_3 = 0.33$	$\varphi_2 = 0.34$	$\varphi_1 = 0.33$
J = 4	$\varphi_4 = 0.25$	$\varphi_3 = 0.25$	$\varphi_2 = 0.25$	$\varphi_1 = 0.25$
		TTP pattern		
J = 2			$\varphi_2 = 0.1$	$\varphi_1 = 0.9$
J = 3		$\varphi_3 = 0.1$	$\varphi_2 = 0.45$	$\varphi_1 = 0.45$
J = 4	$\varphi_4 = 0.1$	$\varphi_3 = 0.30$	$\varphi_2 = 0.30$	$\varphi_1 = 0.30$
		Hump shaped TTB pattern		
J = 3		$\varphi_3 = 0.1$	$\varphi_2 = 0.8$	$\varphi_1 = 0.1$
J = 4	$\varphi_4 = 0.1$	$\varphi_3 = 0.4$	$\varphi_2 = 0.4$	$\varphi_1 = 0.1$
		Declining TTB pattern		
J = 2			$\varphi_2 = 0.8$	$\varphi_1 = 0.2$
J = 3		$\varphi_3 = 0.5$	$\varphi_2 = 0.4$	$\varphi_1 = 0.1$
J = 4	$\varphi_4 = 0.4$	$\varphi_3 = 0.3$	$\varphi_2 = 0.2$	$\varphi_1 = 0.1$

Notes. Values for φ are not applicable for J=2 under the hump shaped TTB spending pattern. In this case we can only consider equal, declining and TTP investment spending patterns.

Table 9: Investment regressions–empirical specification with annual measures: TTP pattern

True $\eta^a = 0.27$			
Coefficient	$J = 2$	$J = 3$	$J = 4$
b_1	3.34	3.19	2.92
	(0.009)	(0.01)	(0.01)
$\widehat{\eta}^a = \frac{1}{b_1}$	*0.30*	*0.31*	*0.34*
$\overline{R}^2$	0.93	0.86	0.75
b_1	2.70	2.35	1.75
	(0.01)	(0.01)	(0.002)
b_2	0.44	0.45	0.50
	(0.006)	(0.007)	(0.01)
$\overline{R}^2$	0.95	0.89	0.80

Notes. The top panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + \varepsilon_t^a$. The bottom panel reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 10: Investment regressions–empirical specification with annual measures: Hump shaped TTB pattern

True η^a = *0.27*			
Coefficient	$J = 2$	$J = 3$	$J = 4$
b_1	n.a.	3.23	3.01
		(0.01)	(0.01)
$\widehat{\eta^a} = \frac{1}{b_1}$	n.a.	*0.31*	*0.33*
$\overline{R}^2$	n.a.	0.92	0.87
b_1	n.a.	2.27	1.99
		(0.01)	(0.01)
b_2	n.a.	0.42	0.67
		(0.006)	(0.02)
$\overline{R}^2$	n.a.	0.95	0.90

Notes. The top panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + \varepsilon_t^a$. The bottom panel reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications. See also notes to Table 8.

Table 11: Investment regressions–empirical specification with annual measures: Declining TTB pattern

True η^a = *0.27*			
Coefficient	$J = 2$	$J = 3$	$J = 4$
b_1	3.44	3.30	3.15
	(0.001)	(0.005)	(0.007)
$\widehat{\eta^a} = \frac{1}{b_1}$	*0.29*	*0.30*	*0.32*
$\overline{R}^2$	0.99	0.96	0.95
b_1	3.26	2.74	2.54
	(0.002)	(0.01)	(0.01)
b_2	0.10	0.25	0.40
	(0.001)	(0.004)	(0.007)
$\overline{R}^2$	0.99	0.98	0.97

Notes. The top panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + \varepsilon_t^a$. The bottom panel reports coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$. In this Table J denotes TTB in quarters. Standard errors are in parenthesis. All statistics are averages over 500 replications.

Table 12: Summary statistics

	All firm - years	Firm-years with $SMALL_{it} = 1$	Firm-years with $SMALL_{it} = 0$
$\frac{I_{it}}{K_{it}}$	0.148	0.146	0.151
	(0.104)	(0.129)	(0.098)
q_{it}	3.57	4.27	3.39
	(4.78)	(6.28)	(4.20)
$\frac{CF_{it}}{K_{it}}$	0.269	0.252	0.273
	(0.35)	(0.46)	(0.30)
$\frac{I_{it-1}}{K_{it}}$	0.130	0.122	0.131
	(0.08)	(0.09)	(0.07)
$(g_{it}^{k})^{-1}$	1.47	1.97	1.20
	(4.20)	(5.88)	(3.06)
Number of employees	5086.25	224.01	6778.4
	(14789.29)	(144.33)	(16844.65)
Real sales	4141.73	180.78	5566.98
	(14199.91)	(176.14)	(16323.29)
Dividend payout ratio	0.216	0.209	0.217
	(2.25)	(0.99)	(2.42)
Number of observations	7091	1950	5141
Number of firms	760		

Notes. The Table reports sample means. Standard deviations in parenthesis. The subscript i indexes firms and t indexes time, where $t = 1980 - 2000$. $SMALL_{it}$ is a dummy variable equal to 1 if firm i belongs to the lower 25th percentile of firms in the sample in terms of number of employees and equal to 0 otherwise.

Table 13: The effects of cash flow on investment: controlling for TTB

Dependent variable: $\frac{I_{it}}{K_{it}}$	OLS (0)	OLS (1)	OLS (2)	OLS (3)	First-diff. GMM (4)	First-diff. GMM (5)
q_{it}	0.006***	0.005***	0.002***	0.003***	0.004***	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\frac{CF_{it}}{K_{it}} * SMALL_{it}$		0.07***	0.023***	n.a.	0.098***	0.014
		(0.01)	(0.01)		(0.02)	(0.02)
$\frac{CF_{it}}{K_{it}} * (1 - SMALL_{it})$		0.06***	0.025***	n.a.	0.036	0.012
		(0.01)	(0.01)		(0.02)	(0.02)
$\frac{I_{it-1}}{K_{it}}$		n.a.	0.29***	0.30***	n.a.	0.19***
			(0.01)	(0.01)		(0.06)
$(g^k_{it})^{-1}$		n.a.	-0.41***	-0.41***	n.a.	-0.55***
			(0.02)	(0.02)		(0.05)
Test on equality of $\frac{CF_{it}}{K_{it}}$ coeff. across small and large firm-years (p-value)		0.14	0.70		0.03	0.91
m_2 (p-value shown)					0.06	0.41
Hansen's J (p-value shown)					0.116	0.652
adjusted R^2	0.21	0.27	0.61	0.60		

Notes. $SMALL_{it}$ is a dummy variable equal to 1 if firm i has employees in the lower 25th percentile (equal to 225 employees) of all firms in the sample and 0 otherwise. A constant, time and industry dummies are included in all specifications although not reported for brevity. Standard errors and test statistics are asymptotically robust to heteroskedasticity. In columns (4) and (5) all right hand side regressors are lagged twice and used as instruments. m_2 is a test for second order serial correlation in the first differenced residuals, asymptotically distributed as N(0,1) under the null of no serial correlation introduced by Blundell et al. (1992). The J statistic is a test of the overidentifying restrictions, distributed as χ^2 under the null of instrument validity. ***Indicates significance at the 1% level.

Table 14: The effects of cash flow on investment: controlling for TTB (alternative classifications (dividend payout))

Dependent variable: $\frac{I_{it}}{K_{it}}$	OLS (0)	OLS (1)	OLS (2)	OLS (3)	First-diff. GMM (4)	First-diff. GMM (5)
q_{it}	0.006***	0.004***	0.002***	0.002***	0.003***	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\frac{CF_{it}}{K_{it}} * SMALL_{it}$		0.07***	0.029***	n.a.	0.058***	0.003
		(0.01)	(0.01)		(0.02)	(0.01)
$\frac{CF_{it}}{K_{it}} * (1 - SMALL_{it})$		0.06***	0.024***	n.a.	0.036	0.021
		(0.01)	(0.01)		(0.03)	(0.02)
$\frac{I_{it-1}}{K_{it}}$		n.a.	0.30***	0.31***	n.a.	0.17***
			(0.01)	(0.01)		(0.05)
$(g^k_{it})^{-1}$		n.a.	-0.40***	-0.41***	n.a.	-0.52***
			(0.02)	(0.02)		(0.05)
Test on equality of $\frac{CF_{it}}{K_{it}}$ coeff. across small and large firm-years (p-value)		0.32	0.31		0.46	0.28
m_2 (p-value shown)					0.02	0.56
Hansen's J (p-value shown)					0.55	0.91
adjusted R^2	0.21	0.27	0.62	0.60		

Notes. $SMALL_{it}$ is a dummy variable equal to 1 if firm i has a dividend payout ratio below the median (equal to 0.22) of all firms in the sample and 0 otherwise. A constant, time and industry dummies are included in all specifications although not reported for brevity. Standard errors and test statistics are asymptotically robust to heteroskedasticity. In columns (4) and (5) all right hand side regressors are lagged twice and used as instruments. m_2 is a test for second order serial correlation in the first differenced residuals, asymptotically distributed as N(0,1) under the null of no serial correlation introduced by Blundell et al. (1992). The J statistic is a test of the overidentifying restrictions, distributed as χ^2 under the null of instrument validity. ***Indicates significance at the 1% level.

Table 15: The effects of cash flow on investment: controlling for TTB (alternative classifications (real sales))

Dependent variable: $\frac{I_{it}}{K_{it}}$	OLS (0)	OLS (1)	OLS (2)	OLS (3)	First-diff. GMM (4)	First-diff. GMM (5)
q_{it}	0.006***	0.004***	0.002***	0.002***	0.004***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\frac{CF_{it}}{K_{it}} * SMALL_{it}$		0.07***	0.024***	n.a.	0.092***	0.025
		(0.01)	(0.01)		(0.02)	(0.01)
$\frac{CF_{it}}{K_{it}} * (1 - SMALL_{it})$		0.07***	0.030***	n.a.	0.038	0.011
		(0.01)	(0.01)		(0.02)	(0.01)
$\frac{I_{it-1}}{K_{it}}$		n.a.	0.30***	0.31***	n.a.	0.17***
			(0.01)	(0.01)		(0.05)
$(g_{it}^k)^{-1}$		n.a.	-0.40***	-0.41***	n.a.	-0.51***
			(0.01)	(0.02)		(0.04)
Test on equality of $\frac{CF_{it}}{K_{it}}$ coeff. across small and large firm-years (p-value)		0.74	0.27		0.02	0.38
m_2 (p-value shown)					0.06	0.55
Hansen's J (p-value shown)					0.54	0.40
adjusted R^2	0.21	0.27	0.62	0.60		

Notes. $SMALL_{it}$ is a dummy variable equal to 1 if firm i has real sales below the 25th percentile (equal to 216.03) of all firms in the sample and 0 otherwise. A constant, time and industry dummies are included in all specifications although not reported for brevity. Standard errors and test statistics are asymptotically robust to heteroskedasticity. In columns (4) and (5) all right hand side regressors are lagged twice and used as instruments. m_2 is a test for second order serial correlation in the first differenced residuals, asymptotically distributed as N(0,1) under the null of no serial correlation introduced by Blundell et al. (1992). The J statistic is a test of the overidentifying restrictions, distributed as χ^2 under the null of instrument validity. ***Indicates significance at the 1% level.

Table 16: Investment regressions–inference and bias

True η^a = *0.27*	True $b_2 = 0$		
Coefficient	$J = 2$	$J = 3$	$J = 4$
I. Baseline TTB			
b_1	2.97	2.55	2.20
Inferred $\widehat{\eta^a} = \frac{1}{b_1}$	*0.34*	*0.39*	*0.45*
estimated b_1 scaled by φ_J	5.94	7.65	8.80
i.e. $b_1 \frac{1}{\varphi_J}$			
Inferred $\widehat{\eta^a} = \frac{\varphi_J}{b_1}$	*0.17*	*0.13*	*0.11*
true bias assuming φ_J is known	-0.10	-0.14	-0.16
b_2	0.22	0.29	0.35
bias in b_2	0.22	0.29	0.35
II. TTP			
b_1	2.70	2.35	1.75
Inferred $\widehat{\eta^a} = \frac{1}{b_1}$	*0.37*	*0.42*	*0.57*
b_1 scaled by φ_J	27	23.5	17.5
i.e. $b_1 \frac{1}{\varphi_J}$			
Inferred $\widehat{\eta^a} = \frac{\varphi_J}{b_1}$	*0.037*	*0.042*	*0.057*
true bias assuming φ_J is known	-0.233	-0.228	-0.213
b_2	0.44	0.45	0.50
bias in b_2	0.44	0.45	0.50
III. Hump shaped TTB			
estimated b_1	n.a.	2.27	1.99
Inferred $\widehat{\eta^a} = \frac{1}{b_1}$	*n.a.*	*0.44*	*0.50*
estimated b_1 scaled by φ_J	n.a.	22.7	19.9
i.e. $b_1 \frac{1}{\varphi_J}$			
Inferred $\widehat{\eta^a} = \frac{\varphi_J}{b_1}$	*n.a.*	*0.044*	*0.05*
true bias assuming φ_J is known	n.a.	-0.232	-0.22
b_2	n.a.	0.42	0.67
bias in b_2	n.a.	0.42	0.67
IV. Declining TTB			
b_1	3.26	2.74	2.54
Inferred $\widehat{\eta^a} = \frac{1}{b_1}$	*0.30*	*0.36*	*0.39*
estimated b_1 scaled by φ_J	4.07	5.48	6.35
i.e. $b_1 \frac{1}{\varphi_J}$			
Inferred $\widehat{\eta^a} = \frac{\varphi_J}{b_1}$	*0.25*	*0.18*	*0.16*
true bias assuming φ_J is known	-0.02	-0.09	-0.11
b_2	0.10	0.25	0.40
bias in b_2	0.10	0.25	0.40

Notes. Each panel reports the coefficients of the regression, $\frac{I_t^a}{K_t^a} = \alpha + b_1 q_t^a + b_2 \frac{\pi_t^a}{K_t^a} + \varepsilon_t^a$ separately reported in Tables 3, 7, 8 and 9. The scaling of the b_1 coefficients are based on the values of φ_J shown in Table 8. In this Table J denotes TTB in quarters.