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Time-to-Build and Convex Adjustment Costs

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Abstract

This paper incorporates time-to-build into the standard investment model with convex adjustment costs. The empirical Euler equation is estimated using a U.S. firm-level panel from Compustat. In spite of the introduction of time-to-build, the magnitude of the implied adjustment costs is unrealistically high. Exploiting another approach, I test directly the restrictions imposed by time-to-build on the investment equation. The results indicate that these restrictions cannot be rejected for five of the sixteen industries in the sample. Finally, I show that time-to-build can explain approximately one-third of the variation in persistence of structures investment across four-digit industries.

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Contents

I. INTRODUCTION

Investment models tell us how to determine the optimal investment path of the firm. In the absence of adjustment costs, the optimal investment expenditures coincide with the change in the desired capital stock in each period. The existence of fixed adjustment costs, on the other hand, gives us lumpy investment. The path of optimal investment is smooth in the convex adjustment costs model. In all cases, the implicit assumption is that the optimal investment path can be implemented instantaneously. In reality, however, most investment projects are not completed overnight. Time-to-build imposes restrictions on the implementation of the optimal investment program and affects the actual path of investment.

The facts about the process of plant investment were presented in previous work (Koeva (2000)). The main empirical findings pertained to the duration and rigidity of time-to-build. First, the gestation lags in investment were approximately two years in most industries. Second, the Lexis-Nexis evidence demonstrated the ex-ante and ex-post inflexibility of the investment in structures. These characteristics of the investment process suggest that time-to-build can be imposed as a rigid technological constraint in a model of firm-level investment.

The typical model estimated in the investment literature is the convex adjustment costs model. In his investment survey, Chrinko (1993) points out that although "delivery, expenditure and gestation lags have been estimated in the literature, [the empirical work in]...this area is relatively unexplored" (p.1905). The goal of this paper is to incorporate time-to-build into the standard model with convex adjustment costs. The empirical specification of the model is derived from the optimization problem of the firm in the presence of time-to-build. The estimation of the dynamic investment model is complicated by the correlation of the lagged dependent variables and the individual effects. Consistent estimation is achieved using the generalized method of moments method developed by Arellano and Bond (1991). Their approach consists of transforming the panel data by orthogonal deviations, and then using suitably lagged endogenous variables as instruments. The empirical equation is estimated using firm-level panel data from Compustat. The implied magnitude of the adjustment costs from the specifications without and with time-to-build suggest that an extra dollar of investment is associated with adjustment costs of 4.27 and 2.70 dollars, respectively.

Using a different approach, I test the restrictions imposed by time-to-build on the investment equation. The closed form solution of this model, proposed by Abel and Blanchard (1986), is obtained by estimating the stochastic process for demand. The restrictions implied by the gestation lag and the process for sales are tested by estimating the constrained and unconstrained forms of the empirical investment equation. The constrained version is not rejected for five of the sixteen industries in the sample.

Finally, the relationship between the length of time-to-build and the persistence of investment at the industry level is examined using data from the NBER Manufacturing Productivity Database and Compustat. The NBER sample contains annual investment data at the four-digit level for 450 manufacturing industries from 1958 until 1993. I estimate a simple second-order autoregressive model for investment at the four-digit industry level and construct a measure of persistence from the impulse response of the system. In particular, I compute the half-life of an exogenous shock. The relationship between the length of time-to-build in months and the persistence of investment is positive and statistically significant. The coefficient estimate suggests that an extra year of time-to-build increases the half-life of a shock by approximately one year. In addition, time-to-build explains about one-third of the industry-level variation in investment persistence. Applying the same methodology to the Compustat sample, I find that differences in construction lead times account for fourteen percent of the variation in investment persistence across two-digit industries.

The paper is organized as follows. Section II provides an overview of the recent findings obtained from the estimation of the convex adjustment costs model. Section III presents the basic model which incorporates convex adjustment costs *and* time-to-build. Section IV derives the empirical specification of the investment equation and discusses the econometric techniques used in the estimation. Section V describes the characteristics of the Compustat sample used in this paper. Section VI presents the main empirical results. The next section explores an alternative specification and estimation of the model. Section VIII examines the effect of time-to-build on the persistence of investment in structures at the industry-level. The last section concludes.

II. Background

The economic models of investment have undergone some interesting changes over the past decades. Most of the investment research during the 1960s and the 1970s focused on the neoclassical model, which derived the optimal level of capital from the maximization problem of the firm, but did not give an explicit consideration to investment dynamics. Delivery lags, time-to-build and other obstacles to the instantaneous adjustment of the capital stock were assumed and added to the empirical specification of the model in order to justify the slow adjustment of investment over time. Nickell (1978) provides a comprehensive survey of the empirical findings of the neoclassical investment model.

The next generation models of investment characterized the optimal path of the capital stock in the presence of convex adjustment costs. The increasing costs at the margin delivered the desired result that the firm should adjust slowly its capital stock to changes in product demand and other exogenous shocks. One of the earliest discussions of the convex adjustment costs model can be found in the work of Eisner and Strotz (1963). The first-order condition for optimal investment, derived from the firm's maximization problem, is the basis for all of the specifications discussed below.[2] The standard assumption in the literature is that the cost function is given by $G(I_t, K_t) = \frac{\gamma}{2}\left(\frac{I_t}{K_t} - c\right)^2 K_t$. Different versions of the convex adjustment costs model became popular in the empirical literature in the early 1980s.

The q model, for example, was estimated by Hayashi (1982), as well as many others. Defining marginal q as the ratio of the shadow value of an additional unit of capital to the price of an additional unit of unused capital, one could derive a relationship between the observed rate of investment and marginal q. Since all expectations about the future are incorporated in the contemporaneous value of marginal q, the theoretical investment equation does not contain any lagged (or any other) variables. The adjustment costs parameter γ can be estimated by regressing the observed rate of investment on the value of q, which is constructed with the use of stock market data.[3] The empirical performance of the model, however, has not been particularly encouraging.

The standard result in the literature is that the coefficient on q is relatively small, i.e. the magnitude of the implied adjustment costs is unreasonably high. In addition, the coefficient estimate is not always statistically significant. To improve the fit of the model, researchers have estimated an augmented qequation, which contains lagged values of average q and the investment rate, as well as other variables. The inclusion of lagged values of q is sometimes justified with the existence of time-to-build. Oliner, Rudenbusch and Sickel (1993) point out, however, that the structural equation that emerges from an investment model with time-to-build is quite different from an empirical specification which contains lags of average q.

Another empirical implementation of the convex adjustment costs model is the Euler equation approach, proposed by Abel (1980). Unlike the previous specification, the estimation of this investment equation does not require the construction and the use of the shadow value of capital. The Euler equation is an intertemporal optimality condition that relates the marginal costs of adjustment across two consecutive periods.[4] The empirical

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[2] The general form of the first-order condition for optimal investment can be written as $\frac{\partial V_t}{\partial K_{t-1}} = -(1-\delta)\frac{\partial \Pi_t}{\partial I_t}$, where δ is the depreciation rate and Π_t, K_t and I_t, denote the firm's cash flow, capital stock and gross investment at time t.

[3] The empirical investment equation typically contains average q, rather than marginal q, as an explanatory variable. Hayashi (1982) demonstrates that under certain conditions, the average and marginal values of q are equivalent.

[4] In the standard investment model without time-to-build, the Euler equation reduces to the condition that the sum of the marginal revenue product of capital and the marginal

(continued...)

specification can be obtained after making appropriate assumptions about the adjustment costs and production functions, and substituting the actual values of the variables for their expected counterparts. The consistent estimation of the model is achieved using instrumental variables. For example, Bond and Meghir (1994) estimate the Euler equation with firm-level investment data from the United Kingdom. Oliner, Rudenbusch and Sickel (1995), on the other hand, examine the forecasting performance of the Euler equation and other investment models.

Abel and Blanchard (1986) offered an alternative method of estimating the convex adjustment costs model. Their approach uses the fact that the shadow value of an additional unit of capital is equal to the expected present value of future marginal revenue products. This sequence of expected future marginal revenue products is substituted with their predictions, generated by an auxiliary forecasting model. The stability of the parameters in the forecasting econometric model is crucial to the success of this estimation method. In another paper, Abel and Blanchard (1988) obtain a closed-form solution to a model with convex adjustment costs and delivery lags by specifying an auxiliary model for the process of demand.[5] The coefficients of the estimated equation depend on the structural parameters of the model.

More recent empirical research has explored yet another approach in order to tackle the empirical implementation of the convex adjustment costs model. The q model has been estimated using a natural experiment methodology. Auerbach and Hassett (1991), Cummins and Hassett (1994) and Cummins, Hassett and Hubbard (1994) are examples of empirical studies which utilize this method. In these papers, the occurrence of tax reforms is used to identify the effect of changing the cost of capital on the level of investment. The magnitude of the adjustment costs implied by the estimates of the coefficient on q is reasonable. Cummins and Hassett (1991), for example, find that an extra dollar of structures investment would lead to approximately 35 cents in adjustment costs. The effect of time-to-build, however, has not been examined by this literature.

The preferred approach in this paper is to estimate an Euler equation which incorporates time-to-build.[6] In particular, I focus on the estimation of a structural equation which is derived from a model with a two-year gestation period. In the second part of the paper, I test the parameter restrictions imposed by time-to-build in the context of the closed-

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adjustment costs in period t must be equal to the discounted expected value of the marginal adjustment costs in period $t+1$.

[5] The role of the cost of capital is not considered in the model. The closed-form solution is derived under the assumption that the model is linear-quadratic.

[6] A version of the Euler equation with time-to-build used here can also be found in Oliner, Rudenbusch and Sickel (1995). In their paper, the model is estimated with aggregate data.

form approach proposed by Abel and Blanchard (1988). The basic model and its empirical specification are presented below.

III. Model

The convex adjustment costs model is standard in the investment literature. I outline the basic model of convex adjustment costs *and* time-to-build below.

Consider a firm which maximized the expected present value of its net revenues:

$$\text{Max } V_t = E\left[\sum_{j=0}^{\infty} \beta_{t+j} \Pi_{t+j} \middle| \Omega_t \right] \tag{1}$$

$$\Pi_t = \Pi(K_t, L_t, I_t) = p_t[F(K_t, L_t) - G(I_t, K_t)] - w_t L_t - p_t^I \tag{2}$$

where β is the discount factor, Π_t is the net cash flow, K_t, I_t and L_t are the capital stock, gross investment and labor input, w_t and p_t^I are the input prices, p_t is the output price, $F(\cdot)$ is the production function and $G(\cdot)$ is the adjustment cost function.

The technology of the investment process is given by the next three constraints:

$$S_{j,t} = S_{j-1,t+1} \tag{3}$$

$$I_t = \sum_{j=1}^{J} \phi_j S_{j,t} \tag{4}$$

$$K_t = (1-\delta) K_{t-1} + S_{1,t} \tag{5}$$

where $S_{j,t}$ denotes an investment project which is *j* periods away from being finished at time *t*, *J* is the length of time-to-build, ϕ_j is the proportion of the total expenditure on project $S_{j,t}$ made in period *t+J-j+1*, $0 \le \phi_j \le 1$ and $\sum \phi_j = 1$.

The firm's optimization problem involves choosing an investment path (namely, a sequence of $S_{J,t}$'s) in order to maximize the expected present value of its net revenues subject to the constraints given by Equations (3) - (5). The problem can be solved using the standard dynamic programming techniques. The value function is defined as follows:

$$V_t(K_t, S_{1,t}, S_{2,t} \ldots S_{J-1,t}) = \max_{L_t, S_{J,t}} \left\{ \Pi(K_t, I_t, L_t) + E\left[\beta_{t+1} V_{t+1}(K_{t+1}, S_{1,t+1}, S_{2,t+1} \ldots S_{J-1,t+1} \middle| \Omega_t \right] \right\} \tag{6}$$

The first-order conditions are described by Equations (7) - (12):

$$\frac{\partial V_t}{\partial K_t} = \frac{\partial \Pi_t}{\partial K_t} + (1-\delta) E\left[\frac{\partial V_{t+1}}{\partial K_{t+1}} \middle| \Omega_t \right] \tag{7}$$

$$\frac{\partial V_t}{\partial S_{1,t}} = \frac{\partial \Pi_t}{\partial I_t} \phi_1 \tag{8}$$

$$\frac{\partial V_t}{\partial S_{2,t}} = \frac{\partial \Pi_t}{\partial I_t} \phi_2 + \beta E\left[\frac{\partial V_{t+1}}{\partial K_{t+1}} + \frac{\partial V_{t+1}}{\partial S_{2,t}} \middle| \Omega_t \right] \tag{9}$$

$$\frac{\partial V_t}{\partial S_{k,t}} = \frac{\partial \Pi_t}{\partial I_t} \phi_k + \beta E\left[\frac{\partial V_{t+1}}{\partial S_{k,t}} \middle| \Omega_t \right] \tag{10}$$

for $k = 3,4,\ldots J\text{-}1$.

$$\frac{\partial \Pi_t}{\partial I_t} \phi_J + \beta E\left[\frac{\partial V_{t+1}}{\partial S_{J,t}} \middle| \Omega_t \right] = 0 \tag{11}$$

$$\frac{\partial \Pi_t}{\partial L_t} = 0 \tag{12}$$

Solving the first-order conditions of the problem, I obtain the following generalized Euler condition:

$$E\left[\sum_{i=1}^{J} \beta^{i-1} \phi_i \frac{\partial \Pi_{t+i-1}}{\partial I_{t+i-1}} \middle| \Omega_t \right] + \beta^{J-1} E\left[\frac{\partial \Pi_{t+J-1}}{\partial K_{t+J-1}} \middle| \Omega_t \right] = \beta(1-\delta) E\left[\sum_{i=1}^{J} \beta^{i-1} \phi_i \frac{\partial \Pi_{t+i}}{\partial I_{t+i}} \middle| \Omega_t \right] \tag{13}$$

The above equation provides the basis for the specification and estimation of the empirical model. Note that in the absence of time-to-build (J=1), the Euler equation takes the familiar form:

$$\frac{\partial \Pi_t}{\partial I_t} + \frac{\partial \Pi_t}{\partial K_t} = \beta(1-\delta)E\left[\frac{\partial \Pi_{t+1}}{\partial I_{t+1}}\middle|\Omega_t\right] \tag{14}$$

IV. Specification and Estimation

A. Empirical Specification

The empirical evidence from Lexis-Nexis (Koeva, 2000) suggests that time-to-build is approximately two years for most of the firms in the Lexis-Nexis sample. The two-period time-to-build specification implies the following Euler equation:

$$\phi_1 \frac{\partial \Pi_t}{\partial I_t} + \beta[\phi_2 - (1-\delta)\phi_1]E\left[\frac{\partial \Pi_{t+1}}{\partial I_{t+1}}\middle|\Omega_t\right] + \beta E\left[\frac{\partial \Pi_{t+1}}{\partial K_{t+1}}\middle|\Omega_t\right] = \beta^2 \phi_2 (1-\delta)E\left[\frac{\partial \Pi_{t+2}}{\partial I_{t+2}}\middle|\Omega_t\right] \tag{15}$$

Let us also assume that $G(I_t, K_t) = \frac{\gamma}{2}\left(\frac{I_t}{K_t} - c\right)^2 K_t$. The production function $F(K_t, L_t)$ is taken to be constant returns to scale in (K_t, L_t). In addition, I allow for imperfect competition with a price elasticity of demand $\xi > 1, \left(\nu = 1 - \frac{1}{\xi}\right)$. Substituting the expression for $\frac{\partial \Pi_t}{\partial I_t}\left(= \gamma\nu p_t c - \gamma\nu p_t \frac{I_t}{K_t} - p_t^I\right)$ in Equation (15), the Euler equation can be re-arranged and written as follows:

$$E\left(\frac{I_{t+2}}{K_{t+2}}\right) = const. + \alpha_1 \frac{p_{t+1}}{p_{t+2}} E\left(\frac{I_{t+1}}{K_{t+1}}\right) + \alpha_2 \frac{p_t}{p_{t+2}} E\left(\frac{I_t}{K_t}\right) - \tag{16}$$

$$-\frac{1}{\gamma}\left[\alpha_3 \frac{p_{t+1}}{p_{t+2}}\left(\frac{\partial \Pi_{t+1}}{\partial K_{t+1}}\right) - \frac{1}{\nu}\frac{p_{t+1}^I}{p_{t+2}}\left(\alpha_1 + \alpha_2 \frac{p_t^I}{p_{t+1}^I} - \frac{p_{t+2}^I}{p_{t+1}^I}\right)\right]$$

where $\alpha_1 \equiv \frac{1}{\beta(1-\delta)} - \frac{\phi_1}{\phi_2}$, $\alpha_2 \equiv \frac{1}{\beta^2(1-\delta)}\frac{\phi_1}{\phi_2}$ and $\alpha_3 \equiv \frac{1}{\beta(1-\delta)\phi_2}$.

Note that the expectational operator is applied everywhere with respect to the information set from period t. The above equation can be simplified even further after using the assumptions that $F(K,L)$ is a constant returns to scale production function $\left(\frac{\partial F}{\partial K}=\frac{Y}{K}-\frac{\partial F}{\partial L}\frac{L}{K}\right)$, and that the marginal product of labor $\frac{\partial F}{\partial L}$ equals the real wage, adjusted for the presence of imperfect competition in the product market. As a result, Equation (16) takes the following form:

$$E\left(\frac{I_{t+2}}{K_{t+2}}\right)=const.+\alpha_1\frac{p_{t+1}}{p_{t+2}}E\left(\frac{I_{t+1}}{K_{t+1}}\right)+\alpha_2\frac{p_t}{p_{t+2}}E\left(\frac{I_t}{K_t}\right)- \tag{17}$$

$$-\frac{1}{2}\alpha_3\frac{p_{t+1}}{p_{t+2}}E\left(\frac{I_{t+1}}{K_{t+1}}\right)^2-\frac{1}{\gamma\nu}\left[\alpha_3\frac{p_{t+1}}{p_{t+2}}E\left(\frac{C_{t+1}}{K_{t+1}}\right)\right]+\left(\frac{1-\nu}{\gamma\nu}\right)$$

$$\left[\alpha_3\frac{p_{t+1}}{p_{t+2}}E\left(\frac{Y_{t+1}}{K_{t+1}}\right)\right]-\frac{1}{\gamma\nu}E\left[\left(\frac{p^I_{t+2}}{p_{t+2}}-\alpha_1\frac{p^I_{t+1}}{p_{t+2}}-\alpha_2\frac{p^I_t}{p_{t+2}}\right)\right]$$

The empirical specification used in this paper is based on Equation (17). Time-specific and firm-specific effects are included as well. The year dummies capture the variation in the user cost, represented by the last term of the above equation. The firm-level heterogeneity in the Compustat sample is taken into consideration by adding company-specific fixed effects. A low-order moving average error term is obtained by substituting the realized values of the variables for their expected counterparts.[7] In particular, I estimate the version of the empirical investment equation given by Equation (18) below:

$$\frac{I_{i,t+2}}{K_{i,t+2}}=f_i+d_{t+2}+\pi_1\frac{I_{i,t+1}}{K_{i,t+1}}+\pi_2\frac{I_{i,t}}{K_{i,t}}+\pi_3\left(\frac{I_{i,t+1}}{K_{i,t+1}}\right)^2+\pi_4\frac{C_{i,t+1}}{K_{i,t+1}}+\pi_{51}\frac{Y_{i,t+1}}{K_{i,t+1}}+u_{i,t+2} \tag{18}$$

[7] The moving-average structure of the error term the estimation of the model and calls for a careful choice of instuments.

The coefficients on the lagged investment rates $\frac{I_{i,t+1}}{K_{i,t+1}}$ and $\frac{I_{i,t}}{K_{i,t}}$ depend on the investment shares ϕ_1 and ϕ_2. The square of the investment rate lagged once appears in the empirical specification because of the quadratic form of the adjustment costs function; the coefficient on this variable is negative and depends on the investment share ϕ_2 as well. The magnitude of the adjustment costs function γ affects the coefficients of the lagged cash flow and output variables, $\frac{C_{i,t+1}}{K_{i,t+1}}$ and $\frac{Y_{i,t+1}}{K_{i,t+1}}$. The sign of the cash flow term should be negative. The output term appears in the empirical investment equation because of the assumption of imperfect competition in the product market. The price elasticity of demand determines the parameter ν which enters the coefficients of the cash flow and output variables. In addition, all coefficients depend on the depreciation rate δ and the discount rate β, which are assumed to be constant over time.

B. Econometric Issues

The problem with estimating the dynamic investment model presented above is the correlation between the lagged dependent variables and the individual effects. Since the conditional expectations are replaced with the actual values of the variables in the empirical specification, the error term $u_{i,t}$ contains a limited amount of serial correlation.

The econometric literature offers several solutions to the problem of estimating consistently the model given by Equation (18). Anderson and Hsiao (1982) propose transforming the model by first-differences and using instrumental variables on the transformed equation. The Anderson-Hsiao approach uses as instruments the first differences of the exogenous regressors, as well as the level or the first difference of appropriately lagged values of the dependent variable. For example, if the error term follows a moving-average process of order q, then $y_{i,t-q-2}$ and $y_{i,t-q-3}$ are suitable instruments.

Arellano and Bond (1991) develop a more efficient method of estimating the model by increasing the number of orthogonality conditions used in the estimation. Their generalized-method-of-moments technique takes into account the autocorrelated structure of the disturbances in the model, as well as the orthogonality between the error term of the transformed equation and further lags of the dependent variable. Using Monte Carlo simulations, Arellano and Bond demonstrate that "the GMM estimator offers significant efficiency gains compared to simple IV alternatives, and produces estimates that are well-determined in dynamic panel models" (p. 293). In addition, the authors present specification tests which could be used after estimating the model.

Consistent estimation is achieved here by using the GMM method developed by Arellano and Bond (1991). The model is estimated using the statistical package DPD

(Dynamic Panel Data) developed by Doornik, Arellano and Bond (1999). The procedure involves transforming the panel data by orthogonal deviations or first differences, and using suitably lagged dependent variables as instruments. In the case of no time-to-build, for example, the untransformed regressors which are lagged two or more periods are valid instruments. A two-year gestation lag implies that only the instruments with lags three or more years should be used. Before discussing the dynamic panel estimation results, however, I describe some of the characteristics of the sample.

V. DATA

Based on the time-to-build data presented in Koeva (2000), I assume that the process of investment takes two years, i.e. the model to be estimated is given by Equation (18). The accounting data on firm-level investment in the United States are available from Compustat. The universe of Compustat firms contains a disproportionate number of large and medium-sized companies. The advantage of Compustat is that the database is easily accessible, and provides investment data over a long period of time.

Before gathering the data on time-to-build from the previous paper, I formed a balanced panel of 1175 Compustat firms. The comprehensive investment data of these companies cover a period of twenty-three years. Most of the annual data are available from 1974 until 1996.[8] The evidence on the characteristics of plant construction was collected for one hundred and six companies, randomly drawn from the Compustat sample. The main findings with respect to the length of time-to-build from Koeva (2000) are reproduced in Table 1.

The estimation of the empirical investment equation, which incorporates a two-period investment process, is based on the Compustat sample. The original panel was restricted using two criteria. First, I use the evidence on time-to-build from Lexis-Nexis to include the companies which come only from industries with two-year gestation lags, i.e. the food products, textile products, lumber, paper products, chemical products, petrol products, leather, glass and stone, fabricated metals, electrical equipment, transportation equipment, measure, freight transportation, water transportation, transport by air, and communications industries. Second, I impose the further restriction that the sample contain only manufacturing firms.[9] The resulting sample consists of five hundred and twenty eight companies.

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[8] Unfortunately, the quarterly database in Compustat starts only in 1983.

[9] The quality of the capital stock series for non-manufacturing firms has been questioned in the investment literature. I exclude these companies in order to ensure the consistency of the empirical results with the previous research on the topic.

Table 1. Average Time-to-Build Across Industries, in months

Industry	Lead time, in months
Food products	24
Textile products	24
Lumber	30
Paper products	23
Chemical products	23
Petrol products	23
Rubber	13
Leather	23
Glass and stone	18
Primary metals	37
Fabricated metals	14
Industrial equipment	18
Electrical equipment	24
Transport equipment	28
Measure	25
Manufacturing, other	18
Railroad transportation	18
Freight transportation	23
Water transportation	25
Transportation by air	24
Communications	24
Utilities	86
Nondurable goods, wholesale	37

The capital stock of the companies is the main variable of interest for the estimation of the model. The Compustat database includes a variable for the capital expenditures of each firm on plant equipment and structures.[10] Based on this accounting information, I use the perpetual inventory method to construct the capital stock variable. The annual depreciation rate is set equal to ten per cent. The annual investment rates of the companies were computed as well. Unfortunately, Compustat does not contain data on output. The variable on sales is used instead.

[10] The Compustat variable for the capital stock in structures had missing values for more than two-thirds of the firms in the sample and covered a shorter period of time.

Before proceeding with the estimation of the model, I take a closer look at the capital stock and investment rate variables. The capital stock of the average firm in the sample is over one billion dollars (the precise value is 1295 million dollars, with a standard deviation of 4797). The capital stock of the median firm, however, is only 75.2 million dollars. The mean and median investment rates are 18 per cent and 16 per cent, respectively. These summary statistics are a reminder that small businesses are not well represented in the Compustat sample.

VI. Results

The estimation results presented in this section have been obtained using the generalized method of moments approach, developed by Arellano and Bond (1991), and described in detail in Section IV. Recall that the Arellano-Bond method consists of transforming the panel data by orthogonal deviations, and then using suitably lagged endogenous variables as instruments.

The investment model from Section III makes some predictions about which instruments should be used in the estimation. If there isn't time-to-build in the model, for example, the instruments from periods t-2, t-3 and t-4 would be valid. The presence of a two-year gestation lag, on the other hand, invalidates the instruments which have been lagged twice.

The results from estimating Equation (18) are summarized in Table 2 below. The first column shows the estimates from a model without time-to-build. The instrument set includes the regressors with two, three and four lags. The Sargan test rejects the overidentifying restrictions. The specification of the Euler equation with time-to-build is considered in the second column of Table 2. The validity of the instrument set which contains regressors from periods t-3 and t-4 is not rejected.

Theory also predicts that the coefficient on the lagged investment rate -- in the absence of time-to-build -- should be at least one. The corresponding estimate, reported in the first column of Table 2, is significantly different from one. In both specifications, the coefficients on the lagged investment rates and the square of the lagged investment rate have the correct sign and are statistically significant. The estimates of the cash flow variable have the right sign in both cases, although its coefficient is not statistically significant in the specification without time-to-build.

Table 2. Euler Equation Estimates

	(1)	(2)
$(I/K)_{t-1}$	0.6318	0.8247
	(0.0511)	(0.1399)
$(I/K)_{t-2}$	-	0.0649
		(0.0246)
$(I/K)^2_{t-1}$	-0.6483	-0.6456
	(0.0863)	(0.2620)
$(Y/K)_{t-1}$	0.0125	0.0134
	(0.0038)	(0.0037)
$(C/K)_{t-1}$	-0.0233	-0.0501
	(0.0380)	(0.0235)
Sargan test	237.3[0.001]	131.0[0.106]

Notes:
1. The dependent variable is the current investment rate.
2. Sargan is a test of overidentification.

The structural parameters implied by the results from the estimation of the empirical investment equation are presented in Table 3. The large magnitude of the adjustment cost parameter γ is the standard problem in the literature. When time-to-build is taken into account, the magnitude of the cost parameter γ decreases but remains unrealistically high. The values of γ from the specifications without and with time-to-build suggest that an extra dollar of investment is associated with adjustment costs of 4.27 and 2.70 dollars, respectively. These computations were done using the mean investment rate in the sample.

Table 3. Structural Parameters

	No Time-to-Build, $J=1$	Time-to-Build, $J=2$
ϕ_1	-	0.05
ϕ_2	-	0.90
λ	27.82	17.59
ν	0.46	0.73

The values of the investment weights ϕ_1 and ϕ_2 make sense once we recall the definition of time-to-build.[11] For example, the design phase may not involve large expenditures but is part of the gestation period as well. Therefore, the estimates of the investment shares, reported in Table 3, are plausible.

VII. Alternative Approach

The above approach has its limitations. First, the structural parameters of the Euler equation investment models are notoriously unstable (see Oliner, Rudenbusch and Sickel, 1995). Second, the role of time-to-build isn't directly evaluated in the estimation. For these reasons, I consider an alternative solution. Namely, the restrictions imposed by time-to-build are tested in the context of the closed-form model proposed by Abel and Blanchard (1986). The structure of their model differs from the approach discussed in the previous sections as follows. The empirical investment equation of the firm is derived from a linear-quadratic cost-minimization problem.[12] The process of demand is assumed to be autoregressive and is estimated using data on sales. In this structural model, the level of current investment is a function of the distributed lag of sales. The number of lagged sales variables in the equation is determined by the order of the autoregressive process for demand and the length of time-to-build. The corresponding coefficients depend on the discount rate, time-to-build and adjustment costs parameters. These restrictions are tested by estimating two versions of the empirical investment equation, constrained and unconstrained.

[11] The values of the investment weights are derived under the assumption that the discount rate equals to 0.9.

[12] In contrast to the specification in Section III, the adjustment costs in their model are quadratic in the total investment expenditures incurred within a period.

Using industry-level estimates of time-to-build from Lexis-Nexis, I apply the method described in the previous paragraph. The Compustat sample and variables used in the estimation have already been described in Section V. The length of time-to-build for each two-digit manufacturing sector is taken from Table 1. As already mentioned, the construction lags in most industries last approximately two years, i.e. $J = 2$. For three industries (rubber, industrial equipment and manufacturing, other), the gestation period is one year. The primary metals industry, on the other hand, has time-to-build of three years. To derive the investment equation for each industry, I need to estimate the AR(n) process for sales at the industry level. The empirical results are obtained using a third-order autoregression. Given the nature of the data, I include firm-level fixed effects in the investment equation. The consistent estimation of the industry-level coefficients on lagged sales is achieved using the Allerano-Bond estimator discussed in Section IV. The constrained and unconstrained regressions are estimated using maximum-likelihood. The joint restrictions implied by time-to-build and the process for sales are not rejected for five of the sixteen sectors. The results are quite sensitive to the estimates of the sales process.

VIII. Time-to-Build and Investment Persistence

In this section of the paper, I examine the relationship between the length of time-to-build and the persistence of investment at the industry level using investment data from two different sources, i.e. the NBER Manufacturing Productivity Database and Compustat. The question is whether time-to-build can account for the persistence in the investment series for structures at the industry level. The suggestive empirical results are presented below.

The evidence is derived from four-digit level investment data contained in the NBER Manufacturing Productivity Database. The complete sample contains annual data at the four-digit level for 450 manufacturing industries from 1958 until 1993. The full description of the MP database can be found in Bartelsman and Gray (1996). The industry-specific investment series for structures are constructed as the net change in the real structures capital stock. Using these data, I estimate a simple second-order autoregressive model for investment at the four-digit industry level. A measure of persistence can be derived from the impulse response of the system. In particular, I compute the half-time of an exogenous shock. The information on time-to-build, on the other hand, comes from Section III of this paper. The Lexis-Nexis firms come from forty four-digit industries.

The relationship between the length of time-to-build in months and the persistence of investment is shown in Figure 1. The positive sign of the relationship can be easily spotted. The coefficient estimate is 0.074 (t-statistic = 3.38). If one controls for the persistence in sales, the time-to-build estimate becomes 0.077 (t-statistic = 3.578). In other words, an extra year of time-to-build increases the persistence of structures investment, as measured by the half-life of a shock, by approximately one year. In addition, time-to-build explains approximately one-third of the industry-level variation in investment persistence.

FIGURE 1. TIME-TO-BUILD AND INVESTMENT PERSISTENCE, NBER DATA

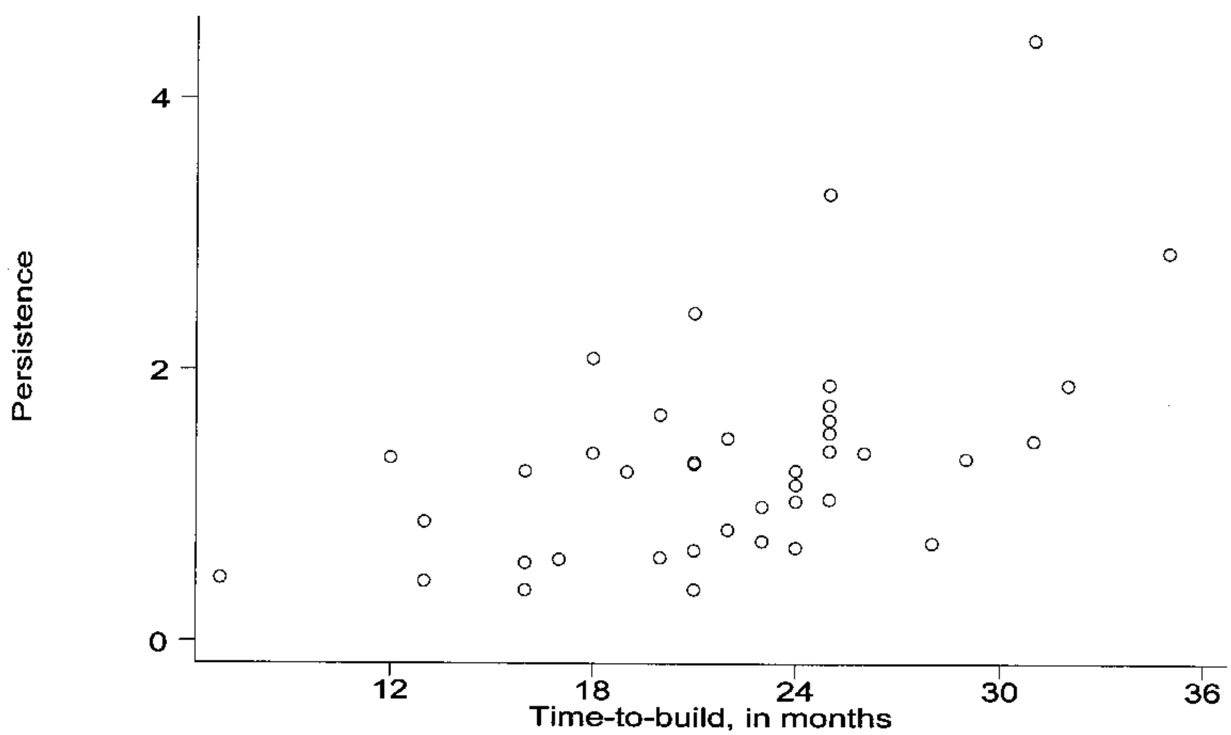
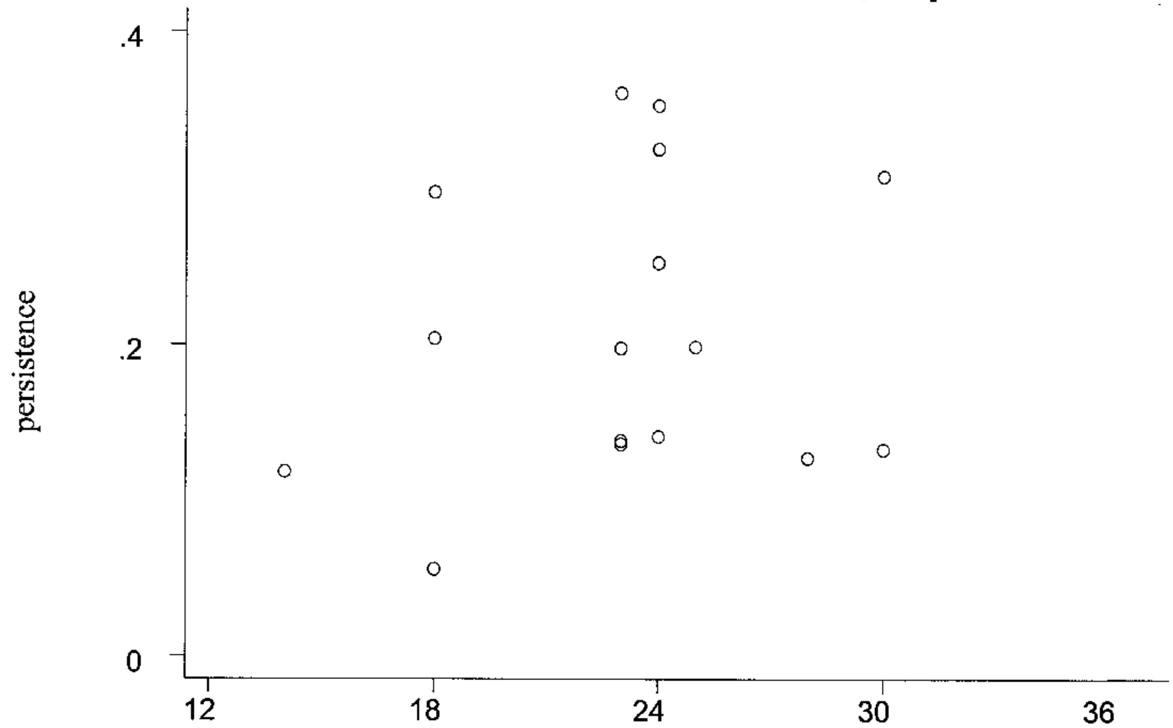


Figure 2. Time-to-Build and Investment Persistence, Compustat Data



The link between time-to-build and persistence can also be examined using the investment data from Compustat. Unfortunately, the capital stock series for structures were available only for approximately one-third of the original sample of 1175 Compustat firms. The firm-specific investment series for structures were computed using the the appropriate capital stock series and industry-level depreciation rates. The sample of manufacturing firms with investment data on structures contains 400 observations. Again, I run a second-order autoregressive process for investment. The estimation is done at the two-digit industry level.

The final results are reported in Figure 2. The horizontal axis displays the values of time-to-build at the two-digit industry level. The vertical axis plots the investment persistence measured by the half-life of an exogenous shock. The number of industries is sixteen. Again, we could detect a positive relationship. In a regression framework, the estimated coefficient of time-to-build is 0.007, with a t-statistic of 1.829. Fourteen percent of the variation in investment persistence across two-digit industries is explained by time-to-build. Therefore, the empirical evidence derived from Compustat also indicates that time-to-build and investment persistence are positively and significantly related.

IX. Conclusion

This paper incorporates time-to-build into the standard model with convex adjustment costs. Deriving an empirical specification from the optimization problem of the firm, I estimate the dynamic investment model with firm-level panel data from Compustat. The consistent estimation of the model is accomplished using the generalized method of moments method developed by Arellano and Bond (1991). The findings suggest that the magnitude of the implied adjustment costs is unrealistically high. Exploiting another approach, I test directly the restrictions imposed by time-to-build on the investment equation. The results indicate that these restrictions cannot be rejected for about one-third of the industries in the sample. Finally, I examine the relationship between time-to-build and investment persistence. The analysis shows that time-to-build can explain approximately one-third of the variation in persistence of structures investment across four-digit industries.

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