Estimating the Euler Equation for Aggregate Investment with Endogenous Capital Depreciation

Eleni Angelopoulou* and Sarantis Kalyvitis†

This article looks at the empirical consequences of introducing endogenous capital depreciation in the standard neoclassical model with quadratic adjustment costs. To this end, we formulate an empirical specification that accommodates capital maintenance and utilization in the Euler equations for aggregate investment. The empirical estimates with data from the Canadian Survey on Capital and Repair Expenditures show that, in contrast to the existing literature, the performance of the Euler equations is improved when we account for the impact of variable capital depreciation.

JEL Classification: D92, E22

1. Introduction

The consensus about the empirical performance of the standard neoclassical aggregate investment model within the context of the profit-maximizing firm facing quadratic adjustment costs is that it can be hardly considered a success story. The two major kinds of specifications for investment that have been tested in the empirical literature, namely, the $q$ model and the Euler equation approach, have soundly failed with aggregate data. Specifically, the Euler equation approach that estimates the first-order condition of the firm, although originally viewed as a promising route, turned out disappointing, as the empirical results have indicated that the overidentifying restrictions are strongly rejected and that high adjustment costs are implied by the estimated regressions, which in turn imply extremely slow adjustment of the capital stock (see, e.g., Chirinko 1993; Whited 1998). This result is corroborated by simulation evidence provided by Shapiro (1986) on the response of the demand for capital to changes in the price of capital and the required rate of return by investors. Moreover, Euler equations are found to exhibit substantial parameter instability (Oliner, Rudebusch, and Sichel 1995).

The purpose of this article is to extend the Euler equation for investment by highlighting the attractive yet unresolved role of endogenous capital depreciation driven by maintenance spending in the determination of aggregate capital expenditures. Our starting point is that firms have two options in raising their productive capacity: by increasing their capital stock through

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“new” investment or by raising capital services through repair or maintenance of the existing capital stock. By completely disregarding this second option, that is, assuming exogenous capital depreciation, a large part of the literature has attempted to explain variations in aggregate investment by relying implicitly on adjustment costs with the latter found to be unreasonably high.\footnote{Several studies have investigated theoretically a setup for the relationship between endogenously determined depreciation and the optimal maintenance level, under which the central decision of the firm involves the allocation of expenditures between “new” investment and maintenance, in order to maximize the discounted value of future income flows by affecting the capital accumulation process either directly or via the depreciation rate. See, among others, Schmalensee (1974), Nickell (1978), Parks (1979), and Schworm (1979) for early contributions in this literature. In turn, there are some empirical studies at the sectoral level that have confirmed that capital deterioration is endogenous and, in particular, associated with maintenance expenditure. Nelson and Caputo (1997) provide a brief survey of the empirical findings and the related literature.} Our study then aims at assessing to what extent the failure of empirical studies of the Euler equation for aggregate investment in providing a plausible assessment of adjustment costs can be attributed to the unexplored role of endogenous capital depreciation. Kalyvitis (2006) showed that the \( q \) model with convex adjustment costs, which accounts for capital maintenance and endogenous depreciation, improved substantially the performance of the \( q \) model by producing significant and plausible parameter estimates for factor demand equations. However, the parameterizations presented in Kalyvitis (2006) aim at estimating reduced-form specifications in which \( q \) explains both “new” investment and maintenance spending. In contrast, the approach adopted here is based on specifications of the first-order conditions through the Euler equations for the firm’s problem, which allow the identification of structural parameters, marginal adjustment costs, and the variable depreciation rate.

The apparent lack of empirical studies with endogenous depreciation driven by capital maintenance is due largely to the unavailability of appropriate aggregate data on maintenance expenditures in most countries. McGrattan and Schmitz (1999) report that evidence from the only source of aggregate long-run data on capital expenditures in newly purchased assets, or “new” investment, and maintenance, namely, the Canadian Survey on Capital and Repair Expenditures, indicates that maintenance expenditures are too big for economists to ignore: total business expenditures in “new” investment and maintenance amounted to 14.1% of GDP in Canada with the average maintenance share covering 27% (3.8% of GDP).

Given these stylized facts, the present article aims at providing a first step to understanding the implications for the empirical implementation of the Euler equation in the standard neoclassical model with quadratic adjustment costs under endogenous capital depreciation affected by the level of spending on capital maintenance. To this end, we develop a theoretical setup for the firm’s decision problem with endogenous depreciation affected by spending on capital maintenance. We then use aggregate data from the Canadian Survey on Capital and Repair Expenditures to estimate the system of structural Euler equations for “new” investment and maintenance. In particular, we estimate the model using alternatively data for the business sector covering the period 1956–1993 and for the manufacturing sector covering the period 1956–2005. Although our results are found to depend on the numerical assumptions for the calibrated parameters, the main finding of the article is that the empirical performance of the Euler equations with variable capital depreciation rate is improved. Including capital maintenance in the depreciation function produces estimates for the adjustment costs that are considerably lower than the values estimated in the aggregate investment literature, whereas we also manage to get plausible values for the average depreciation rate. A by-product of our
empirical estimates is that the depreciation rate in the Canadian economy has exhibited substantial variation. In particular, our findings imply that, depending on the model used, the depreciation rate has varied over the period examined in a range between 1.7 and 3.4 percentage points in the business sector and between 0.7 and 2.6 percentage points in the manufacturing sector. The main picture persists when the depreciation rate is affected by variable capital utilization, an assumption that has been adopted in aggregate models with endogenous depreciation (see, e.g., Greenwood, Hercowitz, and Huffman 1988; Burnside and Eichenbaum 1996).

We stress that our findings on the low estimates for “new” investment adjustment costs are not driven simply by the introduction of an additional friction in the firm’s value function, namely, adjustment costs for maintenance, because these costs are found to be low even when their joint impact with investment adjustment costs is accounted for. Notably, we manage to improve the fit of aggregate investment equations by using the standard framework of convex adjustment costs, which has broadly failed in existing macroeconomic studies of aggregate investment behavior, rather than relying on alternative specifications for adjustment costs.\(^2\)

Regarding the depreciation rate, our point estimates for the average capital depreciation rate across the estimated models for the business and the manufacturing sectors are found to be in the range of 3–7\(^{\circ}\)%, whereas higher depreciation rates are obtained for machinery and equipment. These estimates are not far from those reported by Jorgenson (1996) and Nadiri and Prucha (1996) for the United States.

This article thus contributes to the investment literature by extending the neoclassical investment model with quadratic adjustment costs to account for the impact of endogenous capital depreciation driven by spending on maintenance, a component of capital outlays that has been shown to be important in terms of size and influence but has been largely neglected in the formulation of investment behavior in the level of the macroeconomy. We stress, however, that our setup cannot necessarily characterize or test dynamics at the firm level. Given the aggregate nature of the data at hand, we aim here at assessing whether a simple model with capital spending in “new” investment and maintenance by firms that face identical adjustment cost functions can improve the performance of the investment Euler equation and add to our ability to track and understand capital depreciation at the aggregate level. We would be less optimistic about the performance of a similar approach with quadratic adjustment costs if data at the firm level were available. At the firm level, additional factors, such as the presence of financial constraints for some firms or firm-years, have been suggested as possible reasons for the inadequate performance of the Euler equation. Nevertheless, financing constraints are unlikely to be responsible for such failures at the aggregate level over a long time span.\(^3\)

The rest of the article is structured as follows. Section 2 develops the theoretical model for investment with endogenous capital depreciation and derives the empirical specifications. Section 3 describes the data and the estimation method. Section 4 presents the empirical results, and section 5 concludes the article.

\(^2\) For instance, Christiano, Eichenbaum, and Evans (2005) have shown that an adjustment cost specification that penalizes changes in the level of investment can generate plausible impulse responses to monetary policy shocks. However, Eberly, Rebelo, and Vincent (2008) report that their results tend to favor models based on capital adjustment costs, which seem to outperform the Christiano, Eichenbaum, and Evans (2005) specification in describing investment behavior. Groth (2008) uses a translog cost function approach with convex adjustment costs to estimate the elasticity of investment with respect to \(q\) and reports plausible adjustment costs in the UK manufacturing and service industry.

\(^3\) See, for example, Chatelain and Teurlai (2006) for a detailed discussion.
2. Optimal Capital Spending with Endogenous Depreciation

The Firm’s Problem with Capital Maintenance

Consider the standard partial equilibrium model for the representative firm in which all markets are perfectly competitive and the firm takes factor prices, output prices, and interest rates as given. All input prices are normalized by the price of output. The firm maximizes its value, \( V(.) \), which is a function of the previous-period capital stock, and can influence the pattern of future capital accumulation by appropriately choosing “new” investment and maintenance expenditures. We assume that these two components of capital expenditures have the same price, implying that one unit of “new” investment can be transformed into one unit of maintenance in a costless manner.

The firm’s problem can be summarized as follows:

\[
V_t(K_{t-1}) = \max_{I_t, M_t, L_t} \{ R(K_t, L_t, I_t, M_t) + \beta_t E_t[V_{t+1}(K_t)] \},
\]

where \( K_t \) denotes the capital stock; \( L_t \) denotes labor; \( I_t \) and \( M_t \) denote “new” investment and maintenance expenditures respectively; and \( \beta_t \) is the exogenous time-varying discount factor, so that financing decisions are irrelevant to the optimal path. In turn, net revenues, \( R_t \), are given by

\[
R_t = F(K_t, L_t) - C(K_t, I_t, M_t) - w_t L_t - I_t - M_t,
\]

where \( F(K_t, L_t) \) is the production function with the standard neoclassical properties and \( C(K_t, I_t, M_t) \) denotes adjustment costs driven by spending on “new” investment and maintenance, which will be determined below. In this setup, the firm chooses investment at the beginning of the period when new capital is installed, which becomes immediately operative. The firm also chooses a level of maintenance expenditures for the existing capital stock.

We assume that the law of motion for capital accumulation is given by

\[
K_t = I_t + \left[ 1 - \delta \left( \frac{M_t}{K_{t-1}} \right) \right] K_{t-1},
\]

where the depreciation function has the following general properties: \( \delta'(M_t/K_{t-1}) < 0 \), \( \delta'(M_t/K_{t-1}) > 0 \), \( \lim_{M_t \to 0} \delta(M_t/K_{t-1}) = \delta \), and \( \lim_{M_t \to \infty} \delta(M_t/K_{t-1}) = 0 \). In this setup, \( \delta \) is the rate of depreciation when no maintenance is undertaken, whereas for simplicity we assume that the firm can decrease capital depreciation down to zero.\(^4\) Equation 3 shows that the capital depreciation rate is endogenously determined since by using maintenance expenditures the firm can reduce the depreciation rate of its capital stock and hence carry more units of useable capital to the next period.

The firm’s problem given by Equations 1–3 reduces the infinite-horizon optimization problem to the equivalent two-period problem. The Lagrangean corresponding to the firm’s problem is given by

\(^4\) In principle, we could allow the depreciation rate to approach a constant, as maintenance spending tends to infinity. We abstract from this theoretical consideration, as this would add an extra parameter in our estimates without adding further insights in the empirical results.
\[
\Lambda_t = R(K_t, L_t, I_t, M_t) + \beta_t E_t V_{t+1}(K_t) + \lambda_t \left[ K_t - \left(1 - \delta \left( \frac{M_t}{K_{t-1}} \right) \right) K_{t-1} - I_t \right].
\]

Under perfect competition the first-order conditions are given by\(^5\)

\[
\frac{\partial R_t}{\partial K_t} + \beta_t E_t \frac{\partial V(K_t)}{\partial K_t} + \lambda_t = 0,
\]

\[
\frac{\partial R_t}{\partial I_t} - \lambda_t = 0,
\]

and

\[
\frac{\partial R_t}{\partial M_t} + \lambda_t \delta' \left( \frac{M_t}{K_{t-1}} \right) = 0.
\]

Equations 4 and 5 are the standard optimization conditions, which state that the shadow value of capital, that is, the additional value for the firm from relaxing the constraint given by Equation 3, is equal to the discounted value of current and future revenues generated by an additional unit of capital and that the shadow price of capital \( \lambda_t \) equals the marginal product of investment, which will exceed unity for positive investment in the presence of convex adjustment costs. Equation 6 then emerges as an extra efficiency condition that equates the marginal reduction in revenues due to a rise in maintenance expenditures to the marginal benefit from the reduction in the depreciation of capital, given by \(-\delta'(M/K)\), evaluated at the shadow price of capital.\(^6\)

**Empirical Specification**

To obtain an empirical parameterization of the model, we assume an exponential form for the depreciation function given by

\[
\delta \left( \frac{M_t}{K_{t-1}} \right) = \delta \exp \left[ -\gamma \frac{M_t}{K_{t-1}} \right],
\]

where \( \gamma > 0 \) is a parameter that measures the sensitivity of the depreciation rate with respect to changes in maintenance expenditures.

The first-order condition for capital is now given by

\[
\left[1 - \delta \exp \left[ -\gamma \frac{M_t}{K_{t-1}} \right] \right] \left( \frac{\partial R_t}{\partial K_t} + \beta_t E_t \frac{\partial V(K_t)}{\partial K_t} + \lambda_t \right) = 0.
\]

It follows that, along the optimal path,

\[
\frac{\partial V(K_{t-1})}{\partial K_{t-1}} = -\lambda_t \left[1 - \left(1 + \gamma \frac{M_t}{K_{t-1}}\right) \delta \exp \left[ -\gamma \frac{M_t}{K_{t-1}} \right] \right].
\]

To parameterize the Euler equations, we assume that the firm faces convex installation costs in both types of capital expenditures, namely, “new” investment and maintenance, given

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\(^5\) We omit the first-order condition for labor, which does not affect the empirical specifications derived later.

\(^6\) For similar derivations, see also McGrattan and Schmitz (1999) and Boucekkine and Ruiz-Tamarit (2003).
by
\[ C(K_t, I_t, M_t) = \Psi(K_t, I_t) + \Xi(K_t, M_t), \] (8)
where \( \Psi(K_t, I_t) \) and \( \Xi(K_t, M_t) \) denote adjustment costs in “new” investment and maintenance, respectively, related for instance to installation costs. Although some recent studies have shown that at the plant level adjustment costs are better described by lumpy capital adjustment, the convexity assumption remains reasonable at the aggregate level (Groth 2008). Therefore, we assume that the cost-of-adjustment functions are homogeneously linear in capital, and we follow the standard specification adopted by, among others, Bond and Meghir (1994) and Hubbard (1998), which is given for “new” investment by
\[ \Psi(K_t, I_t) = \frac{\psi}{2} \left( \frac{I_t}{K_t} - \eta_t \right)^2 K_t. \] (9)
Similarly, the adjustment cost function for maintenance is given by
\[ \Xi(K_t, M_t) = \frac{\xi}{2} \left( \frac{M_t}{K_t} - \epsilon_t \right)^2 K_t. \] (10)
The terms \( \eta_t \) and \( \epsilon_t \) denote classical and uncorrelated technology shocks in the adjustment cost functions for investment and maintenance, while \( \psi, \xi \) are positive parameters of the adjustment cost functions.\(^7\)

We can then combine Equations 4–6 to derive the Euler equations for investment and maintenance. To simplify notation, we henceforth use small caps to denote variables divided by capital. Thus, we have \( I_t/K_t = i_t \), \( M_t/K_t = m_t \), while \( \Pi_t/K_t = \pi_t \) is the ratio of profits to the capital stock. The Euler equation for investment can then be written as
\[ i_{t+1} = \frac{1}{\beta_i \varphi_{t+1}} \left( \frac{1 - \beta_i \varphi_{t+1}}{\psi} + i_t + \frac{1}{2} \iota_t^2 + \frac{\xi}{2\psi} m_t^2 + \frac{1}{\psi} \pi_t \right) + v_{1,t+1}, \] (11)
where \( \varphi_{t+1} = 1 - \delta \exp[-\gamma m_t](1 + \gamma m_{t+1}) \) and \( v_{1,t+1} = u_{t+1} + \eta_{t+1} - [1/(2\beta_i \varphi_{t+1})]\eta_t^2 - [\xi(2\beta_i \varphi_{t+1})]v_t^2 - [1/(\beta_i \varphi_{t+1})]\eta_t \).

The Euler equation for maintenance is in turn given by
\[ m_{t+1} = \frac{1}{\beta_i \varphi_{t+1} \rho_{t+1}} \left( \rho_t - \beta_i \varphi_{t+1} \rho_{t+1} + \rho_t m_t + \frac{1}{2} \iota_t^2 + \frac{1}{2\psi} m_t^2 + \frac{\psi}{2\xi} \iota_t^2 + \frac{1}{\xi} \pi_t \right) + v_{2,t+1}, \] (12)
where \( \rho_t = [1/(\gamma \delta)] \exp(\gamma m_t) \), \( v_{2,t+1} = u_{2,t+1} + \epsilon_t - [1/(2\beta_i \varphi_{t+1} \rho_{t+1})]v_t^2 - [\psi(2\beta_i \xi \varphi_{t+1} \rho_{t+1})]\eta_t^2 - [\rho_t/(\beta_i \varphi_{t+1} \rho_{t+1})]v_t \).\(^8\)

An attractive feature of the model is that it nests the model with exogenous depreciation, which is a special case for \( \gamma = 0 \) with a single Euler equation for investment. Hence, any test of the significance of \( \gamma \) is a test on the validity of the key assumption of endogenous depreciation. Equations 11 and 12 form a nonlinear system model that is estimated below.

\(^7\) An interesting extension would be to allow the adjustment costs for “new” investment and maintenance to interact. However, this extension would introduce additional restrictions that would render the empirical specification intractable.

\(^8\) See Angelopoulou and Kalyvitis (2011) for the detailed derivation of Equations 11 and 12.
Empirical Specification with Variable Capital Utilization

A plausible determinant of the depreciation rate supported by some studies is the capital utilization rate. This mechanism is triggered by increased user costs of capital brought about by wear and tear, particularly on equipment, and suggests that capital utilization should be taken into account in conjunction with maintenance expenditures within the context of endogenous capital depreciation.

In this vein, we extend the model outlined in the previous sections to account for the impact of variable capital utilization that affects the depreciation rate of capital and, consequently, enters in the empirical Euler equations for “new” investment and maintenance expenditures. Specifically, we assume that the depreciation rate is affected by the ratio of maintenance expenditures to capital services rather than the capital stock. Hence, using capital more intensively increases the rate at which capital depreciates. The modified depreciation function becomes

\[
\delta \left( \frac{M_t}{u_t K_{t-1}} \right) = \delta \exp \left[ -\gamma \frac{M_t}{u_t K_{t-1}} \right] = \tilde{\delta} \exp \left( -\frac{m_t}{u_t} \right),
\]

where \( u_t \) denotes the capital utilization rate. In contrast to the case of constant depreciation, which implies a zero marginal cost of capital utilization and therefore full capital utilization, the optimality conditions cause the marginal cost of utilization to change along with the marginal product of the underlying accumulated capital stock. This implies that the marginal benefits must be weighed against the marginal costs and that in general firms will not find it optimal to fully utilize their capital stock. The first-order condition for investment Equation 5 remains intact, whereas the first-order conditions for maintenance and utilization become

\[
\frac{\partial R_t}{\partial M_t} - \frac{\gamma}{u_t} \frac{\partial}{\partial u_t} \tilde{\delta} \exp \left[ -\frac{M_t}{u_t K_{t-1}} \right] = 0
\]

and

\[
\frac{\partial F(u_t K_t, L_t)}{\partial (u_t K_t)} \frac{\partial}{\partial u_t} + \lambda_t \frac{\partial}{\partial u_t} \tilde{\delta} \exp \left[ -\frac{M_t}{u_t K_{t-1}} \right] = 0.
\]

In Angelopoulos and Kalyvitis (2011), we show that the Euler equations for “new” investment and maintenance will have a similar structure with the one obtained under variable capital

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11 An interesting extension of the specification for the depreciation function would be to allow maintenance expenditures and utilization to enter with differential impacts; however, adding an extra parameter in the estimated specifications would be a very demanding exercise given the available number of observations. Notice that our results would not be affected if we assumed that the utilization rate enters in the production function as well because of the linear homogeneity of the revenue function in capital. Because of this latter assumption, utilization would not affect the marginal productivity of capital.
utilization with the terms $\phi_{t+1}$ and $\rho_t$, given now by $\phi_{t+1} = 1 - \delta \exp[-\gamma(m_{t+1}u_{t+1})][1 + \gamma(m_{t+1}/u_{t+1})]$ and $\rho_t = [u_t/(\bar{\delta}m_t)] \exp[\gamma(m_tu_t)]$.

Denoting $(\Pi_t) = p_t$ and keeping the notation introduced earlier, the Euler equation for utilization can be written in terms of the profits to the utilization rate as

$$p_{t+1} = \frac{1}{\beta_t(\phi_{t+1}z_{t+1})} \left( \frac{\psi}{2} i_t + \frac{\xi}{2} m_t - z_t p_t - \frac{\psi}{2} \eta_t + \frac{\xi}{2} \epsilon_t \right),$$

(16)

where $z_t = [u_t^2/(\bar{\delta}M_t)] \exp[\gamma(m_tu_t)]$. Equations 11, 12, and 16 yield a system of three Euler equations that is estimated below.

3. Data and Estimation

Equations 11 and 12 make up the baseline model of nonlinear equations to be tested. Our main data source is the Canadian Survey on Capital and Repair Expenditures, which is the only available data set worldwide on aggregate “new” investment and maintenance expenditures. We use aggregate data, available through Canada Statistics, from both the business sector and the manufacturing sector to estimate the empirical equations. The existing studies on empirical investment equations have focused mostly on the manufacturing sector because of data availability and quality issues. The distinction made here provides a robustness test for our conceptual approach and, moreover, allows us to highlight any discrepancies, first, in the magnitude of the estimated adjustment costs for “new” investment and maintenance spending and, second, in the estimated depreciation rates between the aggregate business sector and the manufacturing sector.

In particular, private firms, households, and government organizations in Canada were asked in an annual survey starting in 1956 about their capital and repair expenditures on equipment and structures. The survey is a census with a cross-sectional design and a sample size of 27,000 units; the target population is all Canadian businesses and governments from all the provinces and territories in Canada and the response rate is roughly 85%. Prior to the selection of a random sample, establishments are classified into homogeneous groups (i.e., groups with the same North American Industry Classification System codes, same province/territory, and so on). Business enterprises are defined as those firms where the government controls less than 50% of the voting rights (the remaining of the private sector consists of private institutions and households).

Capital expenditures are gross expenditures on fixed assets and cover spending devoted to “new” investment. These include expenditures on (i) fixed assets (such as new buildings, engineering, machinery, and equipment), which normally have a life of more than one year; (ii) modifications, additions, major renovations, and additions to work in progress; (iii) capital costs, such as feasibility studies and general (architectural, legal, installation, and engineering) fees; (iv) capitalized interest charges on loans with which capital projects are financed; and (v) work by own labor force. Repair expenditures cover spending devoted to capital maintenance and, in specific, (i) maintenance and repair of nonresidential buildings and other structures and on vehicles and other machinery, (ii) building maintenance (janitorial services, snow removal, and sanding), (iii) equipment maintenance (such as oil changes and lubrication of vehicles and machinery), and (iv) repair work by own and outside labor force on machinery and equipment. The survey is conducted after 1993 in an updated form that renders the data on capital and
repair expenditures in the business sector noncomparable. However, we managed to obtain consistent series ending in 2005 for the manufacturing sector.\footnote{Expenditures in capital and repair to capital stock by the manufacturing sector compared to the business sector were roughly steady and amounted between 25\% and 30\% of total capital and repair expenditures for the period 1956–1993. The correlation between the “new” investment and maintenance series is 0.81 for the business sector and 0.69 for the manufacturing sector. See the Data Appendix for a detailed description on the construction of the relevant series.}

Regarding the rest of the variables that enter in Equations 10 and 11, we proxied profits as a proportion of the capital stock from after-tax corporation profits divided by the end-of-period capital stock. Our proxy for profits is based on estimates of factor incomes, which calculate domestic output by measuring incomes accruing to labor (wages, salaries, and supplementary labor income) and capital. The average rate on prime corporate paper was used to calculate the discount factor.\footnote{Following a referee’s advice, we also performed our regressions using the real interest rate to calculate the discount factor.} Table 1 gives a synoptic presentation and some descriptive statistics of the data at hand, and Figure 1A and Figure 1B plot the “new” investment and maintenance series for the business and manufacturing sectors. The average “new” investment to capital ratio was 6.1\% and 6.8\% in the business and manufacturing sectors, whereas the corresponding maintenance-to-capital ratio was 2.25\% and 3.35\%. The volatility of both the “new” investment and maintenance shares has been higher in the manufacturing sector, as indicated by the figures, and the standard deviations and the relative distance between the maximum and minimum values for the periods under consideration.\footnote{In all ratios of the variables to the capital stock, we use the previous-period capital stock to account for the fact that the model requires a beginning-of-period capital stock. See the Data Appendix for a detailed description of the data set and the relevant sources. For an extensive presentation of the data from the Canadian Survey on Capital and Repair Expenditures, see Kalyvitis (2006). Notice that all our series are found to be stationary as indicated by standard unit-root tests.}

Regarding the estimation of Equations 11 and 12, notice that although the expectation error $u_{t+1}$ is uncorrelated with the other two error components, $v_{1,t+1}$ will still be serially correlated as $E(v_{1},v_{1,t+1}) = E[-1/(2\omega_{t+1})\eta_{t}^{2} - 1/(\beta_{t+1})\eta_{t}^{2}]$, which will be generally different from zero, whereas a similar structure is implied for the corresponding error term in the Euler equation for maintenance, $v_{2,t+1}$. Given the complex structure of the system at hand, we use a nonlinear system—generalized method of moments method to estimate simultaneously the two Euler equations (Eqns. 11 and 12). We use as instruments two- to six-period lagged values of the “new” investment and maintenance-to-capital ratios in levels and squared the profits-to-capital ratio and the discount factor. Table 2 reports the correlation coefficients between the main instruments. The correlation of the instruments with the error term is investigated with the standard $J$-test of overidentifying restrictions.

The empirical investigation of the joint determination of depreciation, maintenance expenditures, and capital utilization becomes somewhat difficult because of the lack of data on capital utilization for Canada. Ideally, we would like to have a measure of the capital workweek to approximate the capital utilization rate.\footnote{Shapiro (1986) emphasizes the spurious correlation between capacity utilization and capital utilization and also notices the difficulties associated with the measurement or construction of the latter, as it involves data on the workweek of capital proxied by the number of workers on late shifts, which are not available for the Canadian economy at the aggregate or sectoral level. We notice that Paquet and Robidoux (2001) have introduced a measure of capital utilization in the production function and have found that the Canadian economy can be described by constant returns to scale and perfect competition. Unfortunately, their index can be constructed only from 1970 on.} In the absence of this type of data, we use here the...
industrial (total nonfarm goods–producing industries) capacity utilization rate as a proxy for utilization in the business sector and the manufacturing industries capacity utilization rate for the manufacturing sector. (See the Data Appendix for more details on the sources and the construction of these variables.)

Attempts to estimate the model with freely varying $\delta$ (no-maintenance depreciation rate), $\gamma$ (sensitivity of depreciation to changes in maintenance-to-capital ratio), and $\psi$, $\xi$ (adjustment cost parameters) were unsuccessful. This is not surprising given that there is a clear identification problem between $\delta$ and $\gamma$ since both parameters are related with the curvature of the depreciation function: a higher value of $\delta$ implies that the depreciation function approaches the actual depreciation rate with a larger slope, captured by $\gamma$.

As an alternative strategy, we concentrated on the parameters $\psi$, $\xi$, and fixed $\delta$ by using a range of plausible values, a choice that is motivated mainly by the intuitive consensus on the plausible values for $\delta$, whereas there is no corresponding evidence on $\gamma$. The starting values for parameters $\psi$ and $\xi$ were then set at 0.1, whereas the initial value for parameter $\gamma$ was chosen on the basis of model convergence, which typically resulted in relatively higher initial values of $\gamma$ for higher $\delta$.

Table 1. Descriptive Statistics of Main Variables

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<tbody>
<tr>
<td>“New” investment to capital ratio</td>
<td>0.0607</td>
<td>0.0088</td>
<td>0.0435</td>
<td>0.0784</td>
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<td>Squared “new” investment-to-capital ratio</td>
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<td>0.0019</td>
<td>0.0061</td>
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<td>Maintenance-to-capital ratio</td>
<td>0.0225</td>
<td>0.0025</td>
<td>0.0177</td>
<td>0.0284</td>
<td>0.0335</td>
<td>0.0037</td>
<td>0.0263</td>
<td>0.0413</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squared maintenance-to-capital ratio</td>
<td>0.0005</td>
<td>0.0001</td>
<td>0.0003</td>
<td>0.0008</td>
<td>0.0011</td>
<td>0.0002</td>
<td>0.0007</td>
<td>0.0017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discount factor</td>
<td>0.9281</td>
<td>0.0292</td>
<td>0.8450</td>
<td>0.9694</td>
<td>0.9361</td>
<td>0.0293</td>
<td>0.8451</td>
<td>0.9774</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profits over capital</td>
<td>0.0357</td>
<td>0.0111</td>
<td>0.0087</td>
<td>0.0598</td>
<td>0.1818</td>
<td>0.0717</td>
<td>0.0445</td>
<td>0.4419</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“New” investment-to-capital ratio in machinery and equipment</td>
<td>0.0960</td>
<td>0.0138</td>
<td>0.0723</td>
<td>0.1241</td>
<td>0.0881</td>
<td>0.0170</td>
<td>0.0588</td>
<td>0.1361</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squared “new” investment-to-capital ratio in machinery and equipment</td>
<td>0.0094</td>
<td>0.0027</td>
<td>0.0052</td>
<td>0.0154</td>
<td>0.0080</td>
<td>0.0032</td>
<td>0.0035</td>
<td>0.0185</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance-to-capital ratio in machinery and equipment</td>
<td>0.0474</td>
<td>0.0039</td>
<td>0.0405</td>
<td>0.0570</td>
<td>0.0494</td>
<td>0.0082</td>
<td>0.0359</td>
<td>0.0712</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squared maintenance-to-capital ratio in machinery and equipment</td>
<td>0.0023</td>
<td>0.0004</td>
<td>0.0016</td>
<td>0.0032</td>
<td>0.0025</td>
<td>0.0008</td>
<td>0.0013</td>
<td>0.0051</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: CANSIM database, Statistics Canada, and authors’ calculations.
4. Results

*Aggregate “New” Investment and Maintenance Spending*

Before turning to the estimation of the Euler equation with endogenous capital depreciation, in Table 3 we report for comparison the results from the estimation of the standard Euler equation for investment with constant capital depreciation (see, e.g., Oliner, Rudebusch, and Sichel 1995). The first column corresponds to the business sector sample for...
total investment, and the second and third columns correspond to “new” investment in construction and machinery and equipment, respectively, whereas the estimated coefficient represents the inverse of $\psi$. Estimation is based on the assumption that the depreciation rate is 6.7% for the total capital stock, 5.9% in construction, and 8.2% in machinery and equipment, as reported in Hwang (2002/2003). For all three specifications, the reported coefficient estimates bear the wrong sign, suggesting misspecification despite the fact that the overidentifying restrictions are not rejected (similar findings were obtained by a simple ordinary least squares regression). These results further motivate our attempt to improve the fit

Table 2. Correlation Matrix of Main Variables

<table>
<thead>
<tr>
<th></th>
<th>Business Sector</th>
<th>Manufacturing Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Investment</td>
<td>Investment</td>
</tr>
<tr>
<td>Investment lag</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>Investment lag squared</td>
<td>0.70</td>
<td>0.99</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0.79</td>
<td>0.71</td>
</tr>
<tr>
<td>Maintenance lag</td>
<td>0.54</td>
<td>0.78</td>
</tr>
<tr>
<td>Maintenance lag squared</td>
<td>0.55</td>
<td>0.79</td>
</tr>
<tr>
<td>Profits</td>
<td>0.55</td>
<td>0.80</td>
</tr>
<tr>
<td>Profits lagged</td>
<td>0.20</td>
<td>0.62</td>
</tr>
</tbody>
</table>

All variables are expressed as ratios to the previous-period end capital stock.

Table 3. Estimated Euler Equations with Exogenous Capital Depreciation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Total Capital Stock</th>
<th>Construction</th>
<th>Machinery and Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/\psi$</td>
<td>$-2.86$ (0.20)</td>
<td>$-1.33$ (0.09)</td>
<td>$-4.25$ (0.24)</td>
</tr>
<tr>
<td>Observations</td>
<td>37</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>J-statistic</td>
<td>0.22</td>
<td>0.23</td>
<td>0.25</td>
</tr>
<tr>
<td>Instrument list</td>
<td>$I_K$, $(I_K)^2$, $C_K$, $\beta$</td>
<td>Lags $t-3$ to $t-5$</td>
<td>Lags $t-3$ to $t-5$</td>
</tr>
<tr>
<td>Average depreciation rate</td>
<td>6.7%</td>
<td>5.9%</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

Standard errors are in parentheses. The values reported in the J-test are the probability values of the corresponding test of overidentifying restrictions with $4 \times (n - 1)$ degrees of freedom, where $n$ is the number of lags in the instruments. The depreciation rates are fixed at 6.7% for total capital stock, 5.9% for construction, and 8.2% for machinery and equipment. Marginal adjustment costs are evaluated at the average “new” investment rates.
of the standard Euler equation by endogenizing the depreciation rate following the approach of section 2.

Table 4 reports the estimates of the basic model comprising Equations 11 and 12. The reported average adjustment costs represent the marginal adjustment cost (i.e., $C_I = \psi(I/K)$) evaluated at the average investment rate. The left panel reports the estimates for the business sector with the first column showing the estimates when $\delta = 0.1$. As can be seen, all three parameters $\gamma$, $\psi$, and $\xi$ have the expected sign and small standard errors, whereas the overidentifying restrictions are not rejected. The statistical significance of $\gamma$ supports the endogenous depreciation assumption. The estimated adjustment costs are found to be 44% for “new” investment and 15% for maintenance expenditures. The estimated average depreciation rate is found to be 2.8%, a value that is somewhat low. We perform the same exercise by postulating values $\delta = 0.15$ and $\delta = 0.2$, and the results are presented in the second and third columns of Table 4, respectively. We find again that the model performs well in terms of statistical tests, but the parameter $\gamma$ measuring the response of depreciation to maintenance expenditures is somewhat lower, implying more reasonable average depreciation rates in the range of 6.5–7%.

The right panel of Table 4 presents similar regressions for the manufacturing sector, and again we report three regressions for the same values of $\delta$. The average depreciation rate in the Canadian manufacturing sector is slightly higher compared to the business sector. The evidence corroborates those found for the business sector and are in line with the estimates provided by Jorgenson (1996) and Fraumeni (1997) for the United States, whereas the broad picture indicates that adjustment costs in “new” investment in the manufacturing sector are found to be roughly two times larger than those for maintenance spending and that those for the business sector appear relatively larger and are about three times larger than those for maintenance.

In general, the findings support the model with endogenous depreciation, and the estimated adjustment costs are lower than those provided by the empirical literature on aggregate investment, which are typically found to be implausibly high. Hence, although our results for adjustment costs exhibit a variation in their magnitude depending on the calibrated value for $\delta$, they produce more plausible estimates compared to the existing literature.

To highlight the significance of our estimates for the impact of maintenance expenditures, we calculate the response of depreciation when maintenance expenditures are raised by one standard deviation from their mean value, that is, from 2.25% to 2.5% as a ratio of the capital stock. This rise triggers a fall in the depreciation rate that ranges roughly between 0.37 (for $\delta = 0.1$) and 0.76 (for $\delta = 0.2$) percentage points. Another way to assess these figures is to calculate the difference in the depreciation rate for the maximum and minimum maintenance-to-capital ratios for our sample, which are 1.77% and 2.84%, respectively. Our estimates imply that, depending on the model used, the depreciation rate has varied in a range between 1.7 (for $\delta = 0.1$) and 3.4 (for $\delta = 0.2$) percentage points over the period 1956–1993. A similar picture, although somewhat smaller in magnitude, emerges when the estimates for the manufacturing sector are considered. Following a rise in the maintenance spending-to-capital ratio by one

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16 Jorgenson (1996) reports an average depreciation rate of 15% for durable equipment and 3.1% for nonresidential structures. The figures for durable equipment range between 6.6% (railroad equipment) and 27.3% (office, computing, and accounting machinery). Fraumeni (1997) reports similar figures but has a more detailed categorization; for instance, the depreciation rate for railroad equipment is 5.9%, and for office, computing, and accounting machinery it is 27.3% before 1978 and 31.2% after 1978.

17 An exception is the study by Barnett and Sakellaris (1999) that has estimated the costs of installing new capital to be approximately 10–13% of the total investment cost.
Table 4. Estimated Euler Equations for Aggregate “New” Investment and Maintenance Expenditures

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Business Sector</th>
<th>Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \delta = 0.1 )</td>
<td>( \delta = 0.15 )</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>56.93 (1.24)</td>
<td>33.02 (0.29)</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>14.59 (0.19)</td>
<td>2.03 (0.10)</td>
</tr>
<tr>
<td>( \psi )</td>
<td>13.49 (0.09)</td>
<td>1.98 (0.09)</td>
</tr>
<tr>
<td>Observations</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>J-statistic</td>
<td>0.99</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Instrument list: \( \frac{I}{K}, \frac{M}{K}, \frac{(I/K)^2}{C}, \frac{M}{K} \), \( \beta \).

Estimated marginal adjustment cost for “new” investment:
- \( \delta = 0.1: 44.3\% \)
- \( \delta = 0.15: 6.2\% \)
- \( \delta = 0.2: 0.6\% \)

Estimated marginal adjustment cost for maintenance:
- \( \delta = 0.1: 15.2\% \)
- \( \delta = 0.15: 2.2\% \)
- \( \delta = 0.2: 0.2\% \)

Average depreciation rate:
- \( \delta = 0.1: 2.8\% \)
- \( \delta = 0.15: 7.1\% \)
- \( \delta = 0.2: 6.5\% \)

Initial values for the business sector regressions are \( \delta = 0.1; \gamma = 10; \delta = 0.15; \gamma = 30; \delta = 0.2; \gamma = 50 \) and for the manufacturing sector regressions are \( \delta = 0.1; \gamma = 6; \delta = 0.15; \gamma = 20; \delta = 0.2; \gamma = 25 \). Standard errors are in parentheses. The values reported in the J-test are the probability values of the corresponding test of overidentifying restrictions with \( 6 \times (n - 1) \) degrees of freedom, where \( n \) is the number of lags in the instruments. The marginal adjustment costs evaluated at the average investment and maintenance rates.
standard deviation from 3.35% (sample average) to 3.72%, we find that the fall in the depreciation rate is 0.17 percentage points for $\delta = 0.1$ and 0.57 percentage points for $\delta = 0.2$.

Regarding the sample maximum and minimum maintenance-to-capital ratios (2.63% and 4.13%, respectively), the estimates imply that the depreciation rate in the manufacturing sector has varied between 0.7 (for $\delta = 0.1$) and 2.6 (for $\delta = 0.2$) percentage points over the period 1956–2005.

For comparison, Table 5 reports the results for the business sector based on a second-order approximation of Equations 11 and 12. The results point to slightly higher depreciation rates and lower adjustment costs for both maintenance and new investment. All estimates are statistically significant, and the Hansen test of the overidentifying restrictions rejects misspecification of the instrument set.

Table 6 shows the estimation results when the depreciation function allows for variable capital utilization as given by Equation 13. All the estimated coefficients have the correct sign and are statistically significant. In particular, for $\delta = 0.1$, the average depreciation rate is found to be 7.4%, whereas the adjustment costs for both “new” investment and maintenance are small (3.4% and 1.3% respectively). For $\delta = 0.15$, the depreciation rate is slightly higher (8.1%), and the adjustment costs rise marginally, amounting to 4.6% and 1.7%, whereas for $\delta = 0.2$, the depreciation rate is estimated at 4.6% and the adjustment costs at 51% and 15.5%. Regarding the corresponding estimates for the manufacturing sector, the adjustment costs are found to be higher when capital utilization is taken into account and range between 24.5% and 122.4% for “new” investment and between 12.5% and 50.3% for maintenance, depending on the calibrated value for $\delta$.

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18 We thank a referee for pointing out this alternative estimation strategy.
Table 6. Estimated Euler Equations for Aggregate “New” Investment and Maintenance Expenditures with Variable Capital Utilization

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Business Sector</th>
<th>Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\delta = 0.1$</td>
<td>$\delta = 0.15$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>10.92 (0.08)</td>
<td>22.36 (0.43)</td>
</tr>
<tr>
<td>$\xi$</td>
<td>1.13 (0.02)</td>
<td>1.51 (0.11)</td>
</tr>
<tr>
<td>$\psi$</td>
<td>1.12 (0.02)</td>
<td>1.54 (0.11)</td>
</tr>
<tr>
<td>Observations</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>$J$-statistic</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>Instrument list</td>
<td>$I/K$, $M/K$, $(I/K)^2$, $(M/K)^2$, $C/K$, $\beta$</td>
<td></td>
</tr>
<tr>
<td>Lags t-2 to t-5</td>
<td>Lags t-2 to t-5</td>
<td>Lags t-2 to t-5</td>
</tr>
<tr>
<td>Estimated marginal adjustment cost for “new” investment</td>
<td>3.4%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Estimated marginal adjustment cost for maintenance</td>
<td>1.3%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Average depreciation rate</td>
<td>7.4%</td>
<td>8.1%</td>
</tr>
</tbody>
</table>

The estimates are based on joint estimation of the nonlinear system consisting of Equations 11, 12, and 16. Initial values for the business sector regressions are $\delta = 0.1$: $\gamma = 9$, $\delta = 0.15$: $\gamma = 15$, and $\delta = 0.2$: $\gamma = 25$ and for the manufacturing sector regressions are $\delta = 0.1$: $\gamma = 6$, $\delta = 0.15$: $\gamma = 15$, and $\delta = 0.2$: $\gamma = 25$. See Table 3.
“New” Investment and Maintenance Spending on Machinery and Equipment

A key assumption underlying the estimation of empirical investment models is that capital can be treated as a homogeneous good. Some studies that have relaxed this assumption (e.g., Abel and Eberly 2002) claim that capital heterogeneity may lead to a mismeasurement of the relationship between the various forms of capital and $q$. In an empirical context, Oliner, Rudebusch, and Sichel (1995) have found that investment models for structures perform worse than the corresponding ones for equipment, whereas Bontempi et al. (2004) show that the standard convex costs model performs well for equipment but not for structures where evidence of nonconvex adjustment costs is found.

To account for this distinction we modify our analysis of the Euler equation for “new” investment and maintenance by assuming that only capital expenditures in machinery and equipment are relevant for the firm’s decision between “new” investment and maintenance. The Canadian Survey on Capital and Repair Expenditures distinguishes between nonresidential construction and machinery and equipment expenditures. In particular, spending on machinery and equipment covers (i) automobiles, trucks, professional and scientific equipment, office and store furniture, and appliances; (ii) motors, generators, transformers; (iii) capitalized tooling expenses; and (iv) prepaid progress payments. Looking at the data, we find that the focus on machinery and equipment can be further motivated by the substantial disparities between the two types of assets when their decomposition in the Canadian economy is considered. The bulk of maintenance expenditures by business enterprises involves spending in machinery and equipment (78.5% of total business maintenance outlays are concentrated in machinery and equipment, whereas the corresponding share in “new” investment expenditures is 58.5%). This trend is even more pronounced in the manufacturing sector, where the corresponding figures are 86.4% and 80.7%. The lower panel of Table 1 gives a description of the main statistics for expenditures in machinery and equipment in the business sector and in the manufacturing sector.\(^\text{19}\)

Table 7 presents the results of our estimations on firms’ expenditure for “new” investment and maintenance of machinery and equipment. To identify the model parameters, we need to specify values for the depreciation rate of capital in machinery and equipment under no maintenance, $\delta$. Hwang (2002/2003) finds that the simple overall average rate of the estimated rates of depreciation for structures and machinery and equipment in the Canadian industry sectors are 5.9% and 8.2%, respectively. This picture is broadly confirmed by the evidence provided in the studies by Jorgenson (1996) and Fraumeni (1997) for the United States. We follow the general consensus and assume that the depreciation rates under no maintenance are higher for machinery and equipment, and we set the calibrated values for $\delta$ alternatively at 0.15, 0.2, and 0.25. As can be readily seen, again in all cases the estimated coefficients have the predicted signs and are statistically significant. The estimates for both the business sector and the manufacturing sector produce reasonable figures for the adjustment costs with those for “new” investment estimated at below 16%, being roughly two times larger than the maximum estimates for maintenance adjustment costs (8.1%). Interestingly, the results for machinery and equipment are relatively robust to the choice of $\delta$ and quite similar in magnitude across the two sectors. The average depreciation rate for machinery and equipment in the manufacturing

\(^{19}\) There is no available data for profits stemming from the two types of assets. We therefore estimate Equation 11 and Equation 12 after weighting profits by the corresponding share of the capital stock in machinery and equipment.
sector is generally higher compared to the corresponding one calculated from the specifications with aggregate capital spending.

Finally, Table 8 reports results with variable capital utilization for investment and maintenance expenditures in machinery and equipment. As expected, the depreciation rates estimated here are higher for both sectors compared to the corresponding depreciation rates for total capital, ranging between 6.4% and 13.5% for the business sector and between 5.3% and 11.1% for the manufacturing sector. Following the same pattern as in Table 6, adjustment costs for investment spending on machinery and equipment are higher in the manufacturing sector compared to those in the business sector, ranging between 3% and 5% in the business sector and between 5% and 45% in the manufacturing sector. This also holds for maintenance adjustment costs, which are found to be between 1% and 3% in the business sector and between 3% and 21% in the manufacturing sector.

5. Conclusions

In this article, we have specified and estimated a neoclassical investment model with convex adjustment costs in which firms can spend on capital maintenance that in turn affects the capital depreciation rate. We have estimated jointly the Euler equations for “new” investment and maintenance using data from the Canadian Survey on Capital and Repair Expenditures, and we have shown that the Euler equations perform satisfactorily in terms of
parameter estimates and model identification. Our model gives reasonable estimates for the adjustment costs and the average depreciation rate. These results are not affected by the inclusion of capital utilization in our empirical specifications.

We close the article by pointing out three directions for further research. First, the approach presented here has adopted primarily the size of adjustment costs as the main criterion for the success of the model with endogenous depreciation. However, there are other criteria that have been used in the relevant literature, such as temporal stability (Oliner, Rudebusch, and Sichel 1995) and out-of-sample forecasts. Future research in this area could focus on these aspects of the model with endogenous depreciation and address these issues using the Canadian data on capital and repair expenditures. Second, this article has not addressed the impact of taxation on “new” investment and maintenance expenditures. Typically, maintenance expenditures are treated as current operating expenses and can therefore be fully deducted from pretax revenues, whereas “new” investment expenditures are deducted only through depreciation allowances. Also, policymakers often pursue growth-enhancing policies, such as special tax credits to corporate investment or subsidies to investment loans, which favor spending in “new” investment. Incorporating differential forms

Table 8. Estimated Euler Equations for “New” Investment and Maintenance Expenditures in Machinery and Equipment with Variable Capital Utilization

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Business Sector</th>
<th>Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\delta = 0.15$</td>
<td>$\delta = 0.20$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>1.85 (0.22)</td>
<td>16.04 (0.12)</td>
</tr>
<tr>
<td>$\xi$</td>
<td>0.89 (0.04)</td>
<td>0.58 (0.003)</td>
</tr>
<tr>
<td>$\psi$</td>
<td>0.82 (0.04)</td>
<td>0.57 (0.00)</td>
</tr>
<tr>
<td>Observations</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>J-statistic</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Instrument list</td>
<td>Lags $t-2$</td>
<td>Lags $t-2$</td>
</tr>
<tr>
<td>$I/K$, $M/K$, $(I/K)^2$, $(M/K)^2$, $\beta$</td>
<td>to $t-6$</td>
<td>to $t-5$</td>
</tr>
<tr>
<td>Estimated marginal adjustment cost for “new” investment</td>
<td>4.3%</td>
<td>2.8%</td>
</tr>
<tr>
<td>Estimated marginal adjustment cost for maintenance</td>
<td>1.9%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Average depreciation rate</td>
<td>13.5%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

Initial values for the business sector regressions are $\delta = 0.15$; $\gamma = 10$; $\delta = 0.2$; $\gamma = 12$, and $\delta = 0.25$; $\gamma = 15$ and for the manufacturing sector regressions are $\delta = 0.15$; $\gamma = 7$; $\delta = 0.20$; $\gamma = 12$, and $\delta = 0.25$; $\gamma = 15$. See Table 3.
of taxation and subsidies on capital expenditures in the firm’s problem could offer new insights. Third, it would be of interest to extend the model by examining the links with employment. For instance, if adjustment costs were specified in a more general functional form with interactions between maintenance and labor, the Euler equation would include terms for employment. Likewise, one could introduce variable labor effort (labor hoarding) and assess its implications for the formulation and estimation of the Euler equations for “new” investment and maintenance due to the fact that firms may alter labor utilization by varying hours worked, perhaps jointly with capital maintenance, as these two variables are likely to be linked complementarily in the production process.

Data Appendix

A. “New” Investment and Maintenance Data

The following annual variables in current prices from the Canadian Survey on Capital and Repair Expenditures of Canada Statistics were used to obtain the data for capital and repair expenditures in the aggregate economy and in the manufacturing sector:

(i) Capital and repair expenditures by business enterprises: variable D843800
(ii) Capital expenditures by business enterprises: variable D842986
(iii) Repair expenditures by business enterprises: variable D843801
(iv) Capital expenditures by business enterprises in machinery and equipment: variable D842988
(v) Repair expenditures by business enterprises in machinery and equipment: variable D843803
(ix) Repair expenditures in manufacturing, machinery and equipment, variable v754445 [D878256], 1994–2005, and variable v62550 [D843232], 1956–1993

Backward values for the manufacturing sector up to 1956 were obtained by using the growth rates for capital expenditures (the growth rates for 1992 and 1993 are common for the two surveys) and then by extrapolating the series for repair expenditures through their share in total capital and repair expenditures over 1956–1993.

B. Other Variables

(i) Business capital stock: Business sector end-year gross fixed nonresidential capital stock (Canada Statistics, variable v1408305, Table 031-0002, current prices).
(ii) Business capital stock in machinery and equipment: Business sector end-year gross fixed nonresidential capital stock in machinery and equipment (Canada Statistics, variables v1408308, Table 031-0002, current prices).
(iii) Manufacturing capital stock: Manufacturing sector end-year capital stock, total components, variable v1071434 [D819520], 1955–2007 (Canada Statistics, Table 031-0002, current prices).
(iv) Manufacturing capital stock in machinery and equipment: Manufacturing sector end-year capital stock, variable v1071437 [D819523], 1955–2007 (Canada Statistics, Table 031-0002, current prices).
(v) Interest rate: Average rate on prime corporate paper, 90 days (International Financial Statistics, variable 15660BC.ZF).
(vi) After-tax corporate profits: Nominal corporation profits after taxes, variable v647778 [D23250], 1961–2006 (Canada Statistics, Table 380-0029, current prices), derived by corporation profits before taxes minus (i) interest and miscellaneous investment income paid to nonresidents and (ii) corporate income tax liabilities. Backward values were extrapolated by fitting a linear regression on corporation profits before taxes for all industries, variable v501082 [D11893] (Canada Statistics, Table 380-0048).
(vii) Capital utilization: Industrial (total nonfarm goods-producing industries) capacity utilization rate (Canada Statistics, variables v142812, Table 028-0001, percent), averaged from quarterly data available from 1962 on. Backward values were extrapolated by fitting a linear regression on total fixed nonresidential capital stock for all

(viii) Capital utilization in manufacturing: Manufacturing industries capacity utilization rate, variable v4331088, Table 028-0002, 1987–2006 (Canada Statistics, percent, averaged from quarterly data). Backward values up to 1962 were extrapolated by using the growth rate of the manufacturing industries capacity utilization rate, variable v142817, Table 028-0001 (Canada Statistics, percent, averaged from quarterly data). Backward values up to 1956 were extrapolated by fitting a linear regression on the growth rate of end-year capital stock in manufacturing total components divided by Canada GDP (International Financial Statistics, variable 15699B.CZF).

References


