

Carlsson, Mikael

**Working Paper**

## Investment and Uncertainty: A Theory-Based Empirical Approach

Working Paper, No. 2004:17

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*Suggested Citation:* Carlsson, Mikael (2004) : Investment and Uncertainty: A Theory-Based Empirical Approach, Working Paper, No. 2004:17, Uppsala University, Department of Economics, Uppsala

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Working Paper 2004:17

*Department of Economics*

# Investment and Uncertainty: A Theory-Based Empirical Approach

Mikael Carlsson

Department of Economics  
Uppsala University  
P.O. Box 513  
SE-751 20 Uppsala  
Sweden  
Fax: +46 18 471 14 78

Working paper 2004:17  
October 2004  
ISSN 0284-2904

INVESTMENT AND UNCERTAINTY:  
A THEORY-BASED EMPIRICAL APPROACH

MIKAEL CARLSSON

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# Investment and Uncertainty: A Theory-Based Empirical Approach\*

Mikael Carlsson<sup>†</sup>

October 6, 2004

## Abstract

This paper provides empirical evidence on the dynamic effects of uncertainty on firm-level capital accumulation. A novelty in this paper is that the firm-level uncertainty indicator is motivated and derived from a theoretical model, the neoclassical investment model with time to build. This model also serves as the base for the empirical work, where an error-correction approach is employed. I find a negative effect of uncertainty on capital accumulation, both in the short and the long run. This outcome cannot be explained by the model alone. Instead, the results suggest that the predominant mechanism at work stems from irreversibility constraints.

**Keywords:** Investment; Uncertainty; Dynamic Panel Data Models.

**JEL classifications:** C33; D21; D80; E22.

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\*I am grateful to Susanto Basu, Matz Dahlberg, Per Engström, Stefan Eriksson, Nils Gottfries, Patrik Hesselius, Joakim Jansson and Per Johansson for helpful comments and suggestions. I thank Jan Södersten for providing some of the data. Financial support from the Jan Wallander and Tom Hedelius Foundation is gratefully acknowledged.

<sup>†</sup>Department of Economics, Uppsala University, Box 513, SE-751 20 Uppsala, Sweden. Tel: +46 18 4711131. Fax +46 18 4711478. E-mail: mikael.carlsson@nek.uu.se.

# 1 Introduction

What is the effect on current investments of increased uncertainty about future returns to capital? Theoretically, there is no unambiguous answer to this question. The literature emphasizing the convexity of the marginal returns to capital, e.g. Hartman (1972) and Abel (1983), finds that increased uncertainty should raise investments. In contrast, the literature stressing the irreversibility of capital outlays finds that investments are depressed when uncertainty increases (see e.g. Dixit and Pindyck, 1994). Moreover, the long-run predictions are even more intricate, since the prediction for the short-run effect of increased uncertainty on investment in the irreversible case does not carry over to the long-run stock of capital. Although the short-run effect is negative, the long-run effect is ambiguous in this case (see e.g. Caballero, 1999). Thus, the dynamic effects of uncertainty on capital accumulation constitute an empirical question.

This paper addresses the investment-uncertainty relationship, using a panel of Swedish manufacturing firms.<sup>1</sup> The focus on the firm-level has several advantages relative to studies on more aggregate data, which constitute the majority of the existing literature (see e.g. the survey by Carruth, Dickerson and Henley, 2000). First, a disaggregate measure of uncertainty makes it possible to account for heterogeneous variation in uncertainty, which is likely to cancel out on a more aggregate level. Second, as noted by Carruth et al. (2000), feedback effects from investments to aggregate uncertainty should be a much smaller problem when focusing on the firm-level. Finally, there is the advantage of being able to control for firm-specific heterogeneity through fixed effects.

As a framework for the theoretical and the empirical work, I use a neo-classical investment model. In the benchmark model, it is assumed that the capital stock must be chosen one period in advance, whereas other factors can be adjusted within the period. The motivation for this assumption is that the

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<sup>1</sup>The focus in the paper is on equipment and machinery capital. Henceforth, I will use the term capital synonymously with equipment and machinery capital.

installation of new capital goods is time consuming. Thus, investment outlays today should affect the productive capacity of the capital stock tomorrow.

The benchmark model is used to derive an expression for the desired stock of capital under the assumption that the firm treats expected values as certain. This measure is employed in the empirical specification to capture the investment incentives of the firm if uncertainty was ignored. A cash flow measure is also included to control for potential credit constraints. Finally, a firm-level measure of uncertainty is added to this specification to study the effect of uncertainty on capital accumulation.

A novelty in this paper is that the theoretical model is used to derive a firm-level measure of uncertainty in terms of observables. In general, three different approaches have been taken in the literature to obtain such measures. First, the volatility of the estimated forecast error from a forecasting equation for operating profits is used by von Kalckreuth (2000) and Bo (1999).<sup>2</sup> Relative to these studies, the approach of this paper is a step in the direction of providing micro-foundations for the measure of uncertainty. A Second approach by Guiso and Parigi (1999) and Patillo (1998) is to use survey data on the distribution of managers' subjective perception of uncertainty. Although this measure corresponds closely to what we want to measure, the usual caveats regarding survey data apply. Moreover, the availability of such data is very limited. Finally, several studies, e.g. by Bloom, Bond and van Reenen (2001) and Leahy and Whited (1996), use an uncertainty measure based on the volatility of the firms' stock price. The downside of this approach is that the volatility in stock prices may be driven by speculative bubbles which are unrelated to the rate of return of investment (Shiller, 1989). Furthermore, the sample in such a study is naturally limited to listed companies.

The firm-level uncertainty measure derived in this paper captures the volatility in technology and the price of flexible factors. Increasing the uncertainty about these determinants of the revenue side of the marginal returns to capital

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<sup>2</sup>This approach has also been applied to more aggregate data, e.g. in Ghosal and Loungani (2000) who use U.S. four-digit (SIC) industry data.

will increase investment in the theoretical model. This is due to the convexity of the future marginal returns to capital; since the flexible factor can be adjusted after that the uncertainty has been dispelled, the future marginal revenue of capital will be a convex function in both technology and the price of flexible factors. Increased variation in technology and the price of flexible factors therefore raises the expected marginal revenue of capital. However, if capital is irreversible we expect a counteracting effect (at least in the short-run), stemming from the option value of waiting when future marginal returns to capital are uncertain. When both mechanisms are at work, the net effect is ambiguous (see Pindyck, 1993).

As noted above, the dynamics of the effect of uncertainty on capital accumulation may be quite intricate. To allow for a separation of the short-run effects from the effects on the long-run capital stock, I use an error-correction approach in the empirical work.

The main findings are that (i) uncertainty has a negative effect on capital accumulation in the short as well as in the long run. Thus, the neoclassical model with time to build cannot alone explain the data. Instead, the finding of a negative effect supports the view that the predominant effect stems from irreversible capital expenditures as opposed to the convexity of the future marginal returns to capital channel. (ii) The short-run effect of increased uncertainty is large, whereas the long-run effect is more moderate. The estimates imply that an increase of one (within) standard deviation in the uncertainty measure reduces investment by 16 percent on impact and, if the increase is permanent, the long-run stock of capital will decrease by 2 percent.

Although there is considerable variation in the literature across the measures for capturing uncertainty, the overall evidence points towards a negative investment-uncertainty relationship. Using a theory based specification and firm-level data, this paper adds more evidence in this direction.

The paper is organized as follows. Section 2 presents the benchmark model and derives the desired stock of capital when the firm treats expected values as certain. Section 3 discusses the theoretical predictions for the investment-

uncertainty relationship and derives the uncertainty indicator. Section 4 discusses the data. Section 5 derives the empirical specification and discusses econometric issues. Section 6 presents the results and section 7 concludes.

## 2 Model

The neoclassical model derived in this section draws on Caballero, Engel and Haltiwanger (1995) and Carlsson and Laséen (2002). Let the firm's production function for gross output be:

$$Y_t = A_t K_{t-1}^\gamma F_t^\phi, \quad \gamma > 0, \quad \phi > 0 \text{ and } \gamma + \phi < 1, \quad (1)$$

where  $A$  is an index measuring technology,  $K$  is the stock of capital and  $F$  an index of other flexible factors of production. It is assumed that only the stock of capital is associated with adjustment impediments - all other variable factors,  $F$ , are flexible.<sup>3</sup> Moreover, the production function is assumed to exhibit decreasing returns to scale. In period  $t$ , the firm produces its output, using the capital stock from period  $t - 1$ , where a time period represent a year in this model. The time to build assumption is reasonable because the installation of new capital goods is time consuming (see e.g. Hall (1977) and Nickel (1978) for empirical evidence) and the stock of capital is measured at the end of the period. The timing within each period is as follows: first, shocks are realized and second, adjustments are made to flexible factors and the period's investment decision is made. Third, production takes place and finally, capital adjustments become productive.

The profit for the firm is given by:

$$\Pi_t = Y_t - P_{F,t} F_t - C_t K_{t-1}, \quad (2)$$

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<sup>3</sup>Although this latter assumption can be criticized on grounds of e.g. labor adjustment cost, the main share of production factors other than capital is intermediate materials. Intermediate materials account for about 68 percent of the total costs in Swedish manufacturing (computed using the data underlying Carlsson, 2003), whereas labor accounts for about 25 percent.



where  $P_F$  is the real price of flexible factors and  $C$  is the real cost of capital. Optimizing over flexible factors yields the following first-order condition:

$$F_t = \left( \frac{P_{F,t}}{A_t K_{t-1}^\gamma \phi} \right)^{-\frac{1}{1-\phi}}. \quad (3)$$

Substituting (3) back into (1), gives an expression for output when flexible factors are optimally chosen:

$$Y_t = A_t^{\frac{1}{1-\phi}} P_{F,t}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} K_{t-1}^{\frac{\gamma}{1-\phi}}. \quad (4)$$

Next, a theoretical construct, i.e. the frictionless stock of capital, is defined, which is used to develop a base for the empirical work. Let frictionless capital,  $\tilde{K}_t$ , be defined as the  $K_{t-1}$  the firm would like to have had in period  $t$  after observing the shocks in period  $t$ .  $\tilde{K}_t$  is then given by the  $K_{t-1}$  maximizing (2) s.t. (1), i.e.:

$$\gamma \tilde{K}_t^{-\frac{1-\gamma-\phi}{1-\phi}} A_t^{\frac{1}{1-\phi}} P_{F,t}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} = C_t, \quad (5)$$

where (3) has been used to eliminate flexible factors.  $A_t$  and  $P_{F,t}$  are not directly observable but we can use (4) to eliminate these variables. Combining (4) and (5) yields:

$$\gamma \tilde{K}_t^{-\frac{1-\gamma-\phi}{1-\phi}} Y_t K_{t-1}^{-\frac{\gamma}{1-\phi}} = C_t. \quad (6)$$

Multiplying with  $K_{t-1}$  on both sides of (6) and rearranging yields:

$$\frac{\tilde{K}_t}{K_{t-1}} = \left( \frac{\gamma Y_t}{C_t K_{t-1}} \right)^\eta, \quad (7)$$

where  $\eta = (1 - \phi)/(1 - \gamma - \phi) > 1$ . This expression then gives the ratio of the frictionless stock of capital to the actual stock of capital, in terms of observable variables.

So far, nothing has been said about how the firm actually chooses the stock of capital. Since production takes place with the stock of capital lagged one period, what is of importance for the firm when deciding upon the size of the capital adjustment in period  $t$  is the expectation of the conditions in period  $t + 1$ . If we then make the thought experiment that the firm treats expected

values as certain, the firm would choose the capital stock in  $t$  as:

$$K_t = \left( \frac{1}{\gamma} \frac{E_t(C_{t+1})}{[E_t(A_{t+1})]^{\frac{1}{1-\phi}} [E_t(P_{F,t+1})]^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}}} \right)^{-\eta}, \quad (8)$$

where the latter expression is given by solving (5) for  $\tilde{K}_t$ , forwarding this expression one period and substituting the expected values for the realizations of  $A_{t+1}$ ,  $P_{F,t+1}$  and  $C_{t+1}$ . This type of behavior is labeled the certainty equivalent controller scheme.<sup>4</sup>

I assume that the processes for  $A_t$ ,  $P_{F,t}$  and  $C_t$  can be approximated as  $X_t = X_{t-1}\theta_{X,t}$ , where the shocks  $\theta_{X,t}$  are assumed to have a constant mean over time, but may have a time varying variance. Since the capital choice in period  $t$  is taken after the realization of the shocks in period  $t$ , it follows that  $E_t(X_{t+1}) = X_t E_t(\theta_{X,t+1}) = X_t E(\theta_X)$ . Using this result, (8) can be rewritten as:

$$K_t = \tilde{K}_t \left( \frac{E(\theta_C)}{[E(\theta_A)]^{\frac{1}{1-\phi}} [E(\theta_{P_F})]^{-\frac{\phi}{1-\phi}}} \right)^{-\eta} = \tilde{K}'_t. \quad (9)$$

Thus, if the firm (i) applies a certainty equivalent controller scheme and (ii) does not face any adjustment impediments, but must choose the stock of capital in advance, the desired stock in period  $t$ , i.e.  $\tilde{K}'_t$ , will be equal to the product of the frictionless stock of capital and a constant, which depends on the means of the exogenous shocks to which the firm is subject. Combining (7) and (9), the log deviation between  $\tilde{k}'_t$ , and the actual stock of capital in period  $t$ ,  $k_{t-1}$ , can be expressed as:

$$\tilde{k}'_t - k_{t-1} = \eta [y_t - k_{t-1} - c_t + v], \quad (10)$$

where lower case letters denote the log of the variable and  $v$  is a sum of constants, including expressions of the means of the shocks to the exogenous determinants. Intuitively, expression (10) implies that the deviation between the desired stock of capital under the certainty equivalent controller scheme and the actual stock of capital before adjustment is proportional to the imbalance in a Jorgensonian

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<sup>4</sup>This terminology is taken from the engineering literature on servomechanisms (see e.g. Bertsekas, 1976) where it is used to denote a control scheme where uncertainty about future outcomes is neglected.

(neoclassical) first-order condition for capital. Equation (10) will be used as the base for the empirical work.

### 3 The Effect of Uncertainty

This section first discusses the effects on the optimal choice of capital of dropping the certainty equivalent controller scheme in the environment outlined above. This experiment highlights the effects of the convexity of the future marginal returns to capital. Second, the effects of irreversibility constraints on the capital adjustment process are discussed.

In a frictionless world where the stock of capital is chosen one period ahead, the firm faces the following problem:

$$\max_{K_t} E_t \left\{ (1 - \phi) K_t^{\frac{\gamma}{1-\phi}} A_{t+1}^{\frac{1}{1-\phi}} P_{F,t+1}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} - C_{t+1} K_t \right\}, \quad (11)$$

where (1) and (3) have been substituted into (2). The first-order condition can be written as:

$$E_t \left\{ \gamma K_t^{-\frac{1}{\eta}} A_{t+1}^{\frac{1}{1-\phi}} P_{F,t+1}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} - C_{t+1} \right\} = 0. \quad (12)$$

From (11), it follows that the firm faces three different sources of uncertainty about the future marginal returns to capital, i.e., uncertainty about  $A_{t+1}$ ,  $P_{F,t+1}$  and  $C_{t+1}$ . By assuming that the distribution of the shocks to these processes are independent of each other, (12) can be rewritten as:

$$\gamma K_t^{-\frac{1}{\eta}} A_t^{\frac{1}{1-\phi}} P_{F,t}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}} E_t \left( \theta_{A,t+1}^{\frac{1}{1-\phi}} \right) E_t \left( \theta_{P_{F,t+1}}^{-\frac{\phi}{1-\phi}} \right) - C_t E(\theta_C) = 0, \quad (13)$$

which states that the optimal stock of capital is given by the stock of capital equating the expected marginal revenue of capital with the expected real cost of capital. Since the power of  $K_t$ , i.e.  $-1/\eta$ , is negative, the expected marginal revenue will be a decreasing (convex) function in  $K_t$ . Moreover, the power of  $\theta_{A,t+1}$  is  $1/(1-\phi) > 1$  and the power of  $\theta_{P_{F,t+1}}$  is  $-\phi/(1-\phi) < 0$ , which implies that  $\theta_{A,t+1}^{1/(1-\phi)}$  and  $\theta_{P_{F,t+1}}^{-\phi/(1-\phi)}$  are convex functions in their arguments. By Jensen's inequality, it then follows that  $E_t \left( \theta_{A,t+1}^{1/(1-\phi)} \right)$ , and  $E_t \left( \theta_{P_{F,t+1}}^{-\phi/(1-\phi)} \right)$

are increasing in the the standard deviation of  $\theta_{A,t+1}$  and  $\theta_{P_F,t+1}$ , respectively. Thus, increased uncertainty about future realizations of  $A_{t+1}$  and  $P_{F,t+1}$  raises the expected marginal revenue of capital and, hence, the optimal stock of capital. However, since  $\theta_{C_{t+1}}$  enters (12) linearly, increased uncertainty about the real cost of capital will have no effect on the optimal choice of capital.

To see the underlying intuition for these results, the key insight is that when the flexible factor can be adjusted after shocks have occurred, the *realized* marginal returns to capital will be a convex function in the realizations of technology and the price of flexible factors. However, because the capital stock cannot be adjusted, uncertainty about the real cost of capital is of no importance. That is, the *realized* marginal returns to capital will be a linear function of the realization of the real cost of capital. The positive effect on capital accumulation arising from uncertainty when the future marginal returns to capital is a convex function of the uncertain variable was demonstrated by Hartman (1972), and later extended by Abel (1983).

To capture the uncertainty in technology and the price of flexible factors, the following index is defined:

$$\Psi_t = A_t^{\frac{1}{1-\phi}} P_{F,t}^{-\frac{\phi}{1-\phi}} \phi^{\frac{\phi}{1-\phi}}. \quad (14)$$

Using (4), the index  $\Psi_t$  can be expressed in terms of observables as:

$$\Psi_t = Y_t K_{t-1}^{-\frac{\gamma}{1-\phi}}. \quad (15)$$

The standard deviation of the shocks to  $a_t$  and  $p_{F,t}$ , expressed as a single index, can then be measured from:

$$\xi_{\Psi,t} = \ln \Psi_t - \ln \Psi_{t-1}. \quad (16)$$

In practice, it is assumed that the firm estimates the next periods' standard deviation of the shock from the standard deviation of recent shocks. The current shock is included, since it is assumed that the firm can observe this shock before any decision regarding capital adjustment is made. The standard deviation of shocks to  $a_t$  and  $p_{F,t}$ , i.e.  $\sigma_{\xi_{\Psi,t}}$ , is then computed as the sample standard

deviation of  $\xi_{\Psi,t}$ ,  $\xi_{\Psi,t-1}$  and  $\xi_{\Psi,t-2}$ . From (15) it follows that to compute  $\Psi_t$ , we first need a measure of  $\gamma/(1-\phi)$ . As argued by Caballero et al. (1995),  $1/(1-\alpha)$ , where  $\alpha$  is the average cost share of equipment capital in total revenue, provides a good approximation of  $\eta (= (1-\phi)/(1-\gamma-\phi))$  for a range of reasonable assumptions. Therefore,  $\gamma/(1-\phi)$  is approximated by  $\alpha$ .<sup>5</sup>

The measure  $\sigma_{\xi_{\Psi,t}}$  is the relevant uncertainty measure for the neoclassical firm facing a time to build constraint, described above. Note that  $\Psi_t$  is akin to the firm's capacity utilization. This should be contrasted to what has been used as uncertainty measures previously in the literature, like e.g. stock price volatility or the volatility in the forecast error for operating profits. Although, these latter measures should be positively associated with the volatility in capacity utilization, one should not expect a perfect correlation between them.

If no other mechanism, beside time to build is at work we should, as argued above, expect a positive effect of uncertainty and capital accumulation. A counteracting effect on investment from increased uncertainty arises, however, if capital outlays are sunk costs; i.e. if investments are irreversible. The irreversibility literature emphasizes the option value of postponing an investment project, when capital expenditures are sunk costs.<sup>6</sup> The option value of waiting is increasing in the degree of uncertainty about the future rate of returns from the project. In other words, *ceteris paribus*, higher uncertainty depresses current investment.<sup>7</sup> Though, if the convexity channel is also at work, the net

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<sup>5</sup>Note that  $\gamma/(1-\phi) = (\eta-1)/\eta \approx \alpha$ .

<sup>6</sup>The irreversibility literature was first summarized, and extended, in Dixit and Pindyck (1994).

<sup>7</sup>Although there is no effect on investment of uncertainty about the expected real cost of capital in the base line model, it should affect the investment decision if capital is irreversible. That is, since the option value of waiting will be affected. Given that the variation in the real cost of capital can be controlled for by including time-effects (as argued below), this effect should also be captured by the time-effects. In preliminary work I experimented with including a measure of uncertainty in the real cost of capital, based on a standard neoclassical measure of the latter variable, in the empirical specification. This does not change any of the conclusions and, moreover, the results suggest that this type of uncertainty also has a negative effect on investment.

effect of increased uncertainty on irreversible investment depends on the change in the option value, relative to the positive effect on the expected marginal returns to capital. Dixit and Pindyck (1994, ch. 11) develop a formal model that illustrates this trade-off.

However, even if the option value effect dominates in the short-run, the long-run effect on the capital stock from higher uncertainty is ambiguous in models with irreversible capital. The irreversibility constraint implies, on one hand, that the firm is restrained from adjusting the stock of capital downwards in bad times and, for a given capital stock, increased uncertainty makes it more likely for this constraint to be binding. But, on the other hand, increased uncertainty increases the reluctance to invest in good times. Thus, the net effect on the average, or the long-run, stock of capital is ambiguous (see e.g. Caballero, 1999).

## 4 Data

The data used in this paper is a balanced panel of Swedish manufacturing firms drawn from the *CoSta* database (described in Hansen, 1999). This database is, in turn, based on *Enterprises - Financial Accounts* collected by Statistics Sweden and contains annual data for non-financial firms located in Sweden. Given the availability of data and after standard cleaning procedures, described in Appendix A, the data set consists of 341 firms observed over the period 1979 - 1994. The capital stocks are estimated using the perpetual inventory method (see the Appendix A).

The sample is ended in 1992 in order to avoid the turbulent years following in the aftermath of the abandonment of the fixed exchange rate in November 1992. Then, given the data requirements of the baseline specification and the estimation method applied (see below), the effective sample used in the estimation is 1986 - 1992.

## 5 Empirical Specification

To derive the empirical specification, I start by specifying an expression for the desired stock of capital,  $k_t^*$ . As a base for this, I use the expression for the desired stock of capital under the certainty equivalent controller scheme,  $\tilde{k}_t'$ , presented in equation (10). In the empirical work I take a flexible approach, akin to the approach of Bloom et al. (2001), Mairesse, Hall and Mulkay (1999) and others, by assuming that the variation in the real cost of capital can be controlled for by time effects. The desired stock of capital might also be affected by cash flow effects, working through, e.g., financial constraints by creating a higher required rate of return for external financing (see e.g. Chirinko and Schaller, 1995, for a discussion). Following Bloom et al. (2001), cash flow relative to (lagged) capital,  $cf_t$ , is therefore included in the expression for desired capital to control for cash flow effects. Finally, uncertainty is allowed to affect the desired stock of capital. The desired stock of capital for firm  $i$ , i.e.  $k_{i,t}^*$ , can then be written as:

$$k_{i,t}^* = d_{0,i} + d_1(\eta y_{i,t} + (1 - \eta)k_{i,t-1}) + d_2\sigma_{\xi_\Psi,i,t} + d_3cf_{i,t} + \tau_t, \quad (17)$$

where  $\tau_t$  is a time-specific effect and the constant in (10) is captured in  $d_{0,i}$ , which is a firm-specific fixed effect. That is, the means of the exogenous shocks, included in the constant term  $v$  in (10), are treated as firm-specific. The desired stock of capital in (17) represents the capital choice the firm would make if required to choose its investments one period ahead under uncertainty.<sup>8</sup>

To allow for a separation between the short-run dynamic effects from the effects on the long-run stock of capital, I take an error-correction approach in the empirical work. Error-correction models have been used in several investment studies on micro-data (see e.g. the recent overview by Bond and van Reenen, 2002, and references therein). Following the standard approach, the error-

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<sup>8</sup>If the firm faces any type of adjustment restriction, we need to think of (17) as the capital the firm would choose, given that the adjustment restrictions were lifted in this period but would be binding in all future periods.

correction specification is derived by first specifying the dynamic adjustment mechanism between desired and actual capital as an autoregressive-distributed lag (ADL), i.e.:

$$\begin{aligned} k_{i,t} = & a_{11}k_{i,t-1} + a_{12}k_{i,t-2} + a_{21}(\eta y_{i,t} + (1-\eta)k_{i,t-1}) + a_{22}\sigma_{\xi_{\Psi},i,t} \quad (18) \\ & + a_{23}cf_{i,t} + a_{24}(\eta y_{i,t-1} + (1-\eta)k_{i,t-2}) + a_{25}\sigma_{\xi_{\Psi},i,t-1} + a_{26}cf_{i,t-1} \\ & + a_{0,i} + t_t + u_{i,t}, \end{aligned}$$

where  $a_{0,i}$  is a firm-specific effect,  $t_t$  a time-specific effect and  $u_{i,t}$  a random error. The expression (18) corresponds to an ADL(2,1) function.<sup>9</sup> Rewriting (18) into an error-correction form yields the baseline specification in this paper (see Appendix B for details), i.e.:

$$\begin{aligned} \Delta k_{i,t} = & b_1\Delta k_{i,t-1} + b_2\Delta y_{i,t} + b_3\Delta\sigma_{\xi_{\Psi},i,t} \quad (19) \\ & + b_4\Delta cf_{i,t} + b_5(y_{i,t-1} - k_{i,t-2}) + b_6k_{i,t-2} \\ & + b_7\sigma_{\xi_{\Psi},i,t-1} + b_8cf_{i,t-1} + a_{0,i} + t_t + u_{i,t}. \end{aligned}$$

The long-run solution of (19) is given by (ignoring the constant and the time-effect):

$$k_i = \frac{b_5}{(b_5 - b_6)}y_i + \frac{b_7}{(b_5 - b_6)}\sigma_{\xi_{\Psi},i} + \frac{b_8}{(b_5 - b_6)}cf_i. \quad (20)$$

## 5.1 Econometric Considerations

The first important point to note is that, by construction, the error term,  $u_{i,t}$ , does not include a technology shock, in contrast to the paper by e.g. von Kalckreuth (2000), or any other shocks in the benchmark model above. Here, shocks to the determinants are not treated as a residual; instead they are included in the measure of  $k_{i,t}^*$ .

Second, the empirical specification, (19), includes a lagged dependent variable as well as fixed effects. As pointed out by Nickell (1981), applying the

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<sup>9</sup>The asymmetry in the ADL function is due to the firm's investment incentives being governed by  $k_t^* - k_{t-1}$ , and not by  $k_t^* - k_t$ , in the model derived above.



within transformation yields biased and inconsistent estimates in this situation. Instead, I take the approach suggested by Arellano and Bond (1991). Thus, the fixed effects are eliminated by taking first differences, a procedure that introduces a first-order MA process into the residual, i.e.  $\Delta u_{i,t}$ , which, in turn, implies that the first difference of the lagged dependent variable and the residual will be correlated. This problem is addressed by using instrumental variables techniques. Under the assumption that  $u_{i,t}$  is not serially correlated, levels of  $\Delta k_{i,t-s}$  for  $s \geq 2$  are valid instruments. However, since  $k_{i,t-2}$  is included in (19) and the estimation is performed in first differences only,  $\Delta k_{i,t-s}$  for  $s \geq 3$  are used as level instruments to avoid multicollinearity problems in the "first stage".<sup>10</sup> In line with the first point above, all other variables are treated as exogenous.

As is generally the case for an asymptotically efficient GMM estimation, the instrument set grows by  $t$ . However, lags become less informative as instruments as the lag order increases. To avoid including irrelevant instruments, it is sensible not to include the whole history. Here,  $\Delta k_{i,t-s}$  with  $s \geq 7$  is not included as level instruments in the instrument set, that is, the growth rate of capital for more than five years back is not considered to be informative for the current one.<sup>11</sup>

A concern with the Arellano and Bond (1991) estimator is that the estimated standard errors from the second step may be downward biased in finite samples. However, the estimated standard errors from the first step do not seem to suffer from this problem (see e.g. Arellano and Bond, 1991). I therefore rely on first-step estimates, together with first-step heteroscedasticity robust standard errors.

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<sup>10</sup>That is, since  $k_{i,t-2}$  is included as an exogenous variable in the specification and estimation is performed in first differences,  $\Delta k_{i,t-2}$  will already be included in the instrument set.

<sup>11</sup>The results are insensitive to including additional lags.

## 6 Results

Table 1 presents the estimation results. The Sargan test of the over-identifying restrictions cannot reject the null hypothesis of a correctly specified model and valid instruments in any of the specifications. Moreover, there is no evidence of second-order autocorrelation in the differenced residuals in any of the specifications. Thus, the chosen lag specification seems to be appropriate. In column (1) of table 1, the results from estimating equation (19) are presented. Focusing on the short-run estimates in column (I), we see that increasing the uncertainty indicator has a significantly negative short-run effect on capital growth. The estimate for  $\Delta\sigma_{\xi_{\psi},i,t}$  is -0.22. We can also see that lagged capital growth ( $\Delta k_{i,t-1}$ ) and the output growth terms ( $\Delta y_{i,t}$ ) enter significantly with the expected signs, i.e. -0.42 and 0.12, respectively. When turning to the long-run estimates, we see that the uncertainty indicator has a significantly negative long-run effect on the stock of capital. The long-run estimate for  $\sigma_{\xi_{\psi},i}$  is -0.40. Moreover, the long-run estimate for  $y_i$  is significantly positive, 0.35. It is also interesting to see that the  $(y_{i,t-1} - k_{i,t-2})$  term enters significantly with a positive sign, 0.18, which is consistent with error correction behavior. However, the results do not indicate that cash flow effects are an important determinant of capital growth, neither in the short- nor in the long-run.

The theory outlined in section 3 identifies two counteracting forces on investment from increased uncertainty about technology and the real flexible factor price. There is a positive effect working through the convexity of the future marginal returns to capital and a negative option effect due to irreversible capital expenditures. The observed negative, short-run and long-run, effects on capital accumulation thus support the view that the predominant effect on investment from increased uncertainty stems from the negative option effect as opposed to the convexity channel.

If irreversibility constraints are present, there may also be important nonlinear effects in the short-run responses to investment incentives. To explore this,  $(\Delta y_{i,t})^2$  and  $\Delta y_{i,t}\sigma_{\xi_{\psi},i,t}$  are included in the specification (19). The term

Table 1: Results

	(I)	(II)
$\Delta k_{i,t-1}$	-0.417* (0.167)	-0.406* (0.166)
$\Delta y_{i,t}$	0.123** (0.029)	0.135** (0.041)
$\Delta \sigma_{\xi_{\Psi},i,t}$	-0.219** (0.07)	-0.269** (0.083)
$\Delta cf_{i,t}$	0.022 (0.014)	0.022 (0.014)
$(\Delta y_{i,t})^2$		0.095 (0.052)
$\Delta y_{i,t} \sigma_{\xi_{\Psi},i,t}$		-0.051 (0.056)
$(y_{i,t-1} - k_{i,t-2})$	0.183** (0.049)	0.193** (0.051)
$k_{i,t-2}$	-0.333** (0.125)	-0.314* (0.127)
$\sigma_{\xi_{\Psi},i,t-1}$	-0.206** (0.069)	-0.225** (0.072)
$cf_{i,t-1}$	0.027 (0.016)	0.027 (0.017)
Long-run estimate for $y_i$	0.354** (0.076)	0.381** (0.089)
Long-run estimate for $\sigma_{\xi_{\Psi},i}$	-0.398* (0.178)	-0.443* (0.196)
Long-run estimate for $cf_i$	0.053 (0.041)	0.054 (0.042)
Number of Observations	2387	2387
AR(2) (P-value)	[0.48]	[0.50]
Sargan (P-value)	[0.20]	[0.25]

Notes: Sample 1986-1992 with 341 firms. \* (\*\*) denotes significance at the 5 (1) percent level. The estimation is performed using the Arellano and Bond (1991) GMM system estimator calculated with DPD 1.2 for Ox. See the main text for the instruments used. One-step coefficients with heteroscedasticity robust standard errors in parenthesis. The standard errors for the long-run estimates are computed using the delta method (see Greene, 2000). AR(2) denotes the p-value for the test of second-order autocorrelation in the first differenced residuals. Sargan denotes the p-value of the joint test of model specification and instrument validity. A full set of time dummies is included in both (I) and (II).

$(\Delta y_{i,t})^2$  is included, since changes in investment incentives, for a given level of uncertainty, may have a non-linear effect on capital growth. The term  $(\Delta y_{i,t})^2$

is expected to enter with a positive sign, because irreversibility may prevent the capital stock from falling when investment incentives fall. The term  $\Delta y_{i,t} \sigma_{\xi_{\Psi},i,t}$  is included since increasing the level of uncertainty may reduce the response to a given increase in investment incentives due to increased investment thresholds. The expected sign of  $\Delta y_{i,t} \sigma_{\xi_{\Psi},i,t}$  is then negative. The result from including these two terms in the specification (19) is presented in column (II) of table 1. Although both terms enter with the sign to be expected if capital is irreversible, neither are significant. Another observation is that when comparing the results between columns (I) and (II) of table 1, we see that none of the other estimates are qualitatively affected when these terms are included.

How large are the effects of increased uncertainty? To shed some light on this question, it is informative to calculate the effect of a one-standard deviation increase in  $\sigma_{\xi_{\Psi},i,t}$ . Here, the within standard deviation is used to capture the typical variation for a firm (see the Appendix A). Using the estimates from column (I) in table 1, the results indicate that the growth rate of capital would fall by 1.24 percentage units in the short run (i.e. from a mean growth rate of 7.65 percent per annum). This, in turn, implies that investments would fall by approximately 16 percent on impact. Moreover, if the increase in  $\sigma_{\xi_{\Psi},i,t}$  is permanent, the long-run stock of capital would fall by about 2 percent.<sup>12</sup> Thus, the results indicate that the short-run effect of increased uncertainty is large, whereas the long-run effect is more moderate.

## 7 Concluding Discussion

The theoretical prediction for the investment-uncertainty relationship is ambiguous and the dynamics are potentially quite intricate. The aim of this paper is to provide empirical evidence on this relationship employing a theory based specification on micro-data for Swedish manufacturing firms.

A novelty in this paper is that the firm-level uncertainty indicator is mo-

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<sup>12</sup>This estimate is for an unchanged  $y$ . However, allowing for changes in  $y$  has a very small effect on the result (see Appendix B).

tivated and derived from an investment model. More specifically, I rely on a neoclassical investment model with time to build. This model is also used as the base for the empirical work where an error-correction approach is employed to separate the short-run dynamic effects from the effects on the long-run capital stock.

I find increased uncertainty to have a negative effect on capital accumulation in the short- as well as in the long-run. This cannot be explained by the neoclassical investment model with time to build alone. Instead, the results suggest that the predominant effect on investment of increased uncertainty stems from irreversible capital expenditures. The results in this paper thus add more evidence for the view that there is a negative relationship between investment and uncertainty.

The finding of a negative sign in the investment - uncertainty relationship is in line with a closely related paper by Carlsson and Laséen (2002). Carlsson and Laséen study the capital adjustment process for the same firms as in this paper. One of the main findings is that the actual adjustment patterns are well captured by a stylized model with irreversible capital, thus lending indirect support to the findings here.

I also experiment with allowing for nonlinearities in the short-run responses to investment incentives. It is interesting to see that the signs of these terms are consistent with the presence of irreversibility constraints, though, none of them are statistically significant.

Quantifying the results I find that the short-run effect of increased uncertainty is large, whereas the long-run effect is more moderate. The estimates imply that an increase of one (within) standard deviation in the uncertainty measure gives rise to a fall in the investment level of about 16 percent on impact and, if the increase is permanent, a decline in the long-run stock of capital of 2 percent.

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## 8 Appendix A - Data

The data used in this paper is extracted from the CoSta database, described in Hansen (1999). The sample of firms was first selected as follows:

- Only firms classified within industries 31-38 according to the SNI69 classification system, i.e. the manufacturing sector, are included.
- Only firms that are continuously operating throughout the sample period are included.
- Only firms classified as an ordinary company and an identical/comparable firm from last year in all years are included.

The variables are defined below in terms of those in the CoSta database (see Hansen 1999). To be clear about what is firm-specific and what is industry-specific the sub-index  $j$  for the three-digit industry or, in some cases, two-digit, to which firm  $i$  belongs is introduced.

**Output**  $Y_{i,t} = Var005_{i,t}/PPI_{j,t}$ , where  $Var005$  is operating income and  $PPI$  is a three-digit industry-specific producer price index supplied by Statistics Sweden. For industries where a three-digit producer price index is missing, a two-digit producer price index is instead used.

The **Stock of Capital**  $K_{i,t}$  is the stock of machinery and equipment generated using the perpetual inventory method, i.e.:

$$K_{i,t} = (1 - \delta_j)K_{i,t-1} + I_{i,t}, \quad (21)$$

where  $\delta_j$  is the depreciation rate and  $I_{i,t}$  is investments in machinery and equipment. When calculating three-digit depreciation rates for machinery and equipment, the estimated industry-specific service lives ( $SL_j$ ) are taken from the BEA publication "Fixed Reproducible Tangible Wealth In the United States, 1925-89" and the estimated declining balance rate ( $DBR$ ) for machinery and equipment, assumed to be equal for all manufacturing industries (1.65), is taken from the BEA publication "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929-1995" by Katz and Herman (1997). The depreciation rate

is then calculated as  $\delta_j = DBR/SL_j$ . Unfortunately, in most cases, one must resort to an estimate of the service life for two-digit industries. Investments are defined as  $I_{i,t} = (Var115_{i,t} + Var119_{i,t} - Var127_{i,t})/IPI_{j,t}$ , where  $Var115_{i,t} + Var119_{i,t} - Var127_{i,t}$  is net machinery and equipment capital expenditures,  $IPI_{j,t}$  is the two-digit investment deflator compiled from investment series for machinery and equipment in current and fixed prices collected from SM series N, Statistics Sweden. As starting value for the stock of capital, I use the value according to plan of machinery and equipment ( $Var146_{i,1979}$ ) deflated by  $IPI_{j,1979}$ .

**Cash Flow** ( $CF_{i,t}$ ) is defined as  $Var011_{i,t} + Var016_{i,t} - Var021_{i,t} + Var028_{i,t} - Var047_{i,t}$ , where  $Var011_{i,t}$  is the sum of operating profits before depreciation,  $Var016_{i,t}$  is financial income,  $Var021_{i,t}$  financial expenses,  $Var028_{i,t}$  allocation to untaxed reserves and  $Var047_{i,t}$  is taxes.

For the firm to be included in the sample, I also require it to have a stock of capital and capital expenditures, i.e.  $(Var115_{i,t} + Var119_{i,t})$ , and a market value of sold machinery and equipment, i.e.  $Var127_{i,t}$ , that are non-negative in all time periods, which leaves a sample of 341 firms.

Table 2: Summary Statistics

	Mean	Standard Deviation			Min	Max
		Overall	Between	Within		
$\Delta k_{i,t}$	0.077	0.175	0.065	0.163	-0.752	1.587
$\Delta y_{i,t}$	0.002	0.136	0.051	0.126	-1.271	1.411
$(\Delta y_{i,t} - \Delta c_{j,t})$	0.010	0.167	0.048	0.160	-1.284	1.312
$\Delta \sigma_{\xi_{\Psi},i,t}$	0.003	0.058	0.015	0.057	-0.324	0.718
$\Delta cf_{i,t}$	-0.052	0.720	0.138	0.706	-15.578	10.672
$(y_{i,t} - k_{i,t-1})$	1.684	0.682	0.616	0.294	-0.983	3.945
$(y_{i,t} - k_{i,t-1} - c_{j,t})$	3.050	0.671	0.605	0.292	0.624	5.288
$k_{i,t}$	9.771	1.374	1.353	0.249	5.764	13.999
$\sigma_{\xi_{\Psi},i,t}$	0.096	0.086	0.063	0.059	0.002	1.170
$cf_{i,t}$	0.660	0.789	0.541	0.576	-7.653	17.887

Notes: Sample 1986-1992 with 341 firms.

In table 2, I report some summary statistics for the variables used in the paper. Each variable is decomposed into a between ( $\bar{x}_i$ ) and a within ( $x_{i,t} - \bar{x}_i + \bar{x}$ ) where  $\bar{x}$  is the overall mean. The within and between standard deviations do not sum to the overall standard deviation, since the small sample corrected variance estimates on which they are based are corrected with different factors.

## 9 Appendix B - Derivation of the Error-Correction Model

The derivation of the error-correction specification follows the standard approach and starts by specifying the dynamic adjustment mechanism between  $k$  and  $k^*$  as an autoregressive-distributed lag (ADL):

$$\begin{aligned} k_{i,t} = & a_{11}k_{i,t-1} + a_{12}k_{i,t-2} + a_{21}(\eta y_{i,t} + (1-\eta)k_{i,t-1}) + a_{22}\sigma_{\xi_{\Psi},i,t} \quad (22) \\ & + a_{23}cf_{i,t} + a_{24}(\eta y_{i,t-1} + (1-\eta)k_{i,t-2}) + a_{25}\sigma_{\xi_{\Psi},i,t-1} + a_{26}cf_{i,t-1} \\ & + a_{0,i} + t_t + u_{i,t}, \end{aligned}$$

where an asymmetric lag structure (i.e. an ADL(2,1)) is used. This structure is consistent with the model outlined above, where the capital adjustment incentives are governed by  $k_{i,t}^* - k_{i,t-1}$  and not by  $k_{i,t}^* - k_{i,t}$ . Taking standard steps, (22) can be rewritten as:

$$\begin{aligned} \Delta k_{i,t} = & (a_{11} - 1)\Delta k_{i,t-1} + a_{21}\Delta(\eta y_{i,t} + (1-\eta)k_{i,t-1}) + a_{22}\Delta\sigma_{\xi_{\Psi},i,t} \quad (23) \\ & + a_{23}\Delta cf_{i,t} + (a_{21} + a_{24})(\eta y_{i,t-1} + (1-\eta)k_{i,t-2} - k_{i,t-2}) \\ & + (a_{21} + a_{24} + a_{11} + a_{12} - 1)k_{i,t-2} + (a_{22} + a_{25})\sigma_{\xi_{\Psi},i,t-1} \\ & + (a_{23} + a_{26})cf_{i,t-1} + a_{0,i} + t_t + u_{i,t}. \end{aligned}$$

The expression (23) can be rewritten as:

$$\begin{aligned} \Delta k_{i,t} = & (a_{11} - 1 + a_{21}(1-\eta))\Delta k_{i,t-1} + a_{21}\eta\Delta y_{i,t} + a_{22}\Delta\sigma_{\xi_{\Psi},i,t} \quad (24) \\ & + a_{23}\Delta cf_{i,t} + (a_{21} + a_{24})\eta(y_{i,t-1} - k_{i,t-2}) \\ & + (a_{21} + a_{24} + a_{11} + a_{12} - 1)k_{i,t-2} + (a_{22} + a_{25})\sigma_{\xi_{\Psi},i,t-1} \\ & + (a_{23} + a_{26})cf_{i,t-1} + a_{0,i} + t_t + u_{i,t}, \end{aligned}$$

where all terms containing  $\Delta k_{i,t-1}$  have been collected. This is useful since this term needs to be instrumented (see section 5 above). The reduced form

error-correction specification is then given by:

$$\begin{aligned}\Delta k_{i,t} = & b_1 \Delta k_{i,t-1} + b_2 \Delta y_{i,t} + b_3 \Delta \sigma_{\xi_\Psi, i, t} \\ & + b_4 \Delta cf_{i,t} + b_5 (y_{i,t-1} - k_{i,t-2}) + b_6 k_{i,t-2} \\ & + b_7 \sigma_{\xi_\Psi, i, t-1} + b_8 cf_{i,t-1} + a_{0,i} + t_t + u_{i,t},\end{aligned}\tag{25}$$

where:

$$\begin{aligned}b_1 &= (a_{11} - 1 + a_{21}(1 - \eta)), & b_2 &= a_{21}\eta, \\ b_3 &= a_{22}, & b_4 &= a_{23}, \\ b_5 &= (a_{21} + a_{24})\eta, & b_6 &= (a_{21} + a_{24} + a_{11} + a_{12} - 1), \\ b_7 &= (a_{22} + a_{25}), & b_8 &= (a_{23} + a_{26}).\end{aligned}$$

The long-run solution of the ADL is given by (ignoring the constant and the time effect):

$$\begin{aligned}k_i = & a_{11}k_i + a_{12}k_i + a_{21}\eta y_i + a_{21}(1 - \eta)k_i + a_{22}\sigma_{\xi_\Psi, i} + a_{23}cf_i \\ & + a_{24}\eta y_i + a_{24}(1 - \eta)k_i + a_{25}\sigma_{\xi_\Psi, i} + a_{26}cf_i.\end{aligned}\tag{26}$$

Rewriting (26), we see that the long-run parameters are given by:

$$k_i = \frac{(a_{21} + a_{24})\eta}{\Gamma} y_i + \frac{(a_{22} + a_{25})}{\Gamma} \sigma_{\xi_\Psi, i} + \frac{(a_{23} + a_{26})}{\Gamma} cf_i,\tag{27}$$

where  $\Gamma = (1 - a_{11} - a_{12} - a_{21} - a_{24} + (a_{21} + a_{24})\eta)$ . In terms of the reduced form parameters of (25), the long-run solution can be written as:

$$k_i = \frac{b_5}{(b_5 - b_6)} y_i + \frac{b_7}{(b_5 - b_6)} \sigma_{\xi_\Psi, i} + \frac{b_8}{(b_5 - b_6)} cf_i.\tag{28}$$

Since there will be a drift in  $k$  due to the drift in exogenous variables we need to think about the long-run solution in (28) as the  $k$  the firm would chose in the long-run given the values of the exogenous variables today (including the values for  $\sigma_{\xi_\Psi}$  and  $cf$ ) and if these values would prevail in all future periods.

Note that the long-run solution in (28) is for a constant  $y$ , but if  $k$  changes  $y$  will change. However, as argued below, this should have a very small impact on the results. Expression (4) implies the following long-run relation between  $y$  and  $k$ :

$$y = \frac{\gamma}{1 - \phi} k + \lambda,\tag{29}$$

where we have used that the long-run solution maps the long-run solution of endogenous variables for the value of the exogenous determinants today - thus in (29)  $a$  and  $p_F$  (i.e. the log of technology and the prices of flexible factors) are treated as constant and included in the constant  $\lambda$ . Then using (29) to substitute for  $y$  in (28) yields (again ignoring constants):

$$k_i = \Lambda \frac{b_7}{(b_5 - b_6)} \sigma_{\xi_\Psi, i} + \Lambda \frac{b_8}{(b_5 - b_6)} c f_i, \quad (30)$$

where:

$$\Lambda = \left[ 1 - \frac{b_5}{(b_5 - b_6)} \left( \frac{\gamma}{1 - \phi} \right) \right]^{-1}. \quad (31)$$

Using the results presented in table 1 and the same approximation for  $\frac{\gamma}{1-\phi}$  as in section 3, i.e.  $\frac{\gamma}{1-\phi} \approx \alpha$ , where  $\alpha$  is the average cost share of equipment capital in total revenue, we find that  $\Lambda = (1 - 0.354 * 0.065)^{-1} = 1.024$ . Thus, allowing for  $y$  to change when calculating the long-run effect on  $k$  from an increase in  $\sigma_{\xi_\Psi}$  will have a very small effect on the result.

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