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# Estimating Investment Equations in Imperfect Capital Markets

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# Estimating Investment Equations in Imperfect Capital Markets\*

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## Abstract

Numerous studies have tried to provide a better understanding of firm-level investment behaviour using econometric models. The model specification of more recent studies has been based on two main approaches. The first, the real options approach, focuses on irreversibility and uncertainty in perfect capital markets; of particular interest is the range of inaction caused by sunk costs. The second, the neo-institutional finance theory, emphasises capital market imperfections and firms' relaxed liquidity constraints. Empirical applications of the latter theory often refer to linear econometric models to prove these imperfections and thus do not account for the range of inaction caused by irreversibility. In this study, a generalised Tobit model based on an augmented  $q$  model is developed with the intention of considering the coexistence of irreversibility and capital market imperfections. Simulation-based experiments allow investigating the properties of this model. It can be shown how disregarding irreversibility reduces effectiveness of simpler linear models.

**Keywords:**  $q$  model, uncertainty, capital market imperfections, generalised Tobit model

**JEL Classification:** D81, D92, C51

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# 1 Introduction

The understanding of farm investment behaviour is important for economic and policy analysis in agriculture. Investments change farm size, the adoption of new technologies affects the efficiency of farms, and (dis)investments are the main driving forces of structural change in agriculture. This paper aims to improve the understanding of investment behaviour.

Empirical results based on the classical static investment model have so far not been satisfying (SCHIANTARELLI 1995). This model is defined as a factor demand model for a representative firm maximising its value subject to the development of the capital stock over time. Assuming perfect capital markets finance is not connected with the investment decision. Along the optimal path of investments, the cost of acquiring an additional unit of capital is equal to the shadow value of capital,  $q$ . Further improvements focus on additional costs when adjusting the capital stock. These are assumed to be strictly convex in order to ensure a smooth and linear optimal path of investments. The well known  $q$  model and the respective dynamic Euler equation approach are special cases of these dynamic factor demand models (BOND and VAN REENEN 2003). Two main strands of literature focus on further developments in order to improve the understanding of investment behaviour. In particular, the assumptions of perfect capital markets and strictly convex adjustment costs are questioned, as these assumptions do not allow capturing observed phenomena like a high reluctance to invest or frequent periods of inactivity.

The real options approach, which has a close relationship to the stochastic adjustment cost models, gives explanations for observed lumpiness and investment rigidity even though the firm has not reached its desired or target capital stock (see also CABALLERO 1997). Lumpy investments mean in this context that investments are undertaken in a relatively short period of time followed by periods of zero investment. The presence and interaction of irreversible investments, uncertain future revenues and the flexibility in the investment decision lead to a range along the optimal path of investment in which waiting is optimal (DIXIT and PINDYCK 1994). In other words, investment is influenced by the value of the real option to invest whereby delaying the investment becomes optimal. In this context, irreversible investment is caused by fixed costs in adjusting the capital stock, while partial irreversibility occurs when the sale and purchase prices of capital differ. This wedge introduces a piecewise linear function of the adjustment costs which kinks at zero investment (HAMERMESH and PFANN 1996). ABEL and EBERLY (1994; 1996) provide an extended  $q$  model and show thereby that strictly convex adjustment costs cannot explain investment rigidity.

In contrast, the second approach – the neo-institutional finance theory – explicitly considers imperfect capital markets. Asymmetric information and agency problems induce additional transaction costs leading to different interest rates for debt and equity capital, and unequal capital prices for firms as well as uncertain future expectations (SCHIANTARELLI 1995). In this context, maximisation of firms' net income is subject to additional restric-

tions, e.g., financing constraints. A firm is constrained if an increase in internal finance sources causes an increase in investment. Hence, investment is strongly influenced by internal financing abilities and sub-optimal compared to a perfect capital market. A widely used approach is to proxy the missing information in  $q$  by additional explanatory variables. As a consequence, investment and financial decisions are not separable. A comprehensive survey about capital market imperfections is given by HUBBARD (1998).

To our knowledge literature does not provide empirical work about irreversible investment in imperfect capital markets (LENSINK and BO 2001). In order to improve the understanding of farm level investment behaviour we suggest a non-linear model specification to account for irreversibility and coexistent capital market imperfections affecting the investment activity. Thereby we aim to identify the expected bias when either one of the aspects sunk costs in connection with uncertainty or capital market imperfections is not considered in empirical investment models. For this purpose we refer to ABEL and EBERLY (1994) and broaden this model to take additionally financial variables into account. Based on this we derive an econometric model, which controls for the range of inaction and capital market imperfections. By using simulated data we intend to show the advantage of the more generalised model in order to understand empirical investments. Therefore, additionally a simpler linear model is estimated serving as a benchmark for the generalised specification.

The remainder of this paper is organised as follows. After a literature review of empirical work about investments we present the normative investment model. Subsequently, we derive the appropriate econometric model specification and apply this model to simulated data. The paper closes with a brief summary and conclusions.

## **2 Review of Empirical Investment Literature**

Empirical investment literature aims to find evidence for hypotheses derived from the aforementioned theoretical concepts. The  $q$  model in its simplest form assumes perfect capital markets and strictly convex costs attached to adjusting the capital stock and regresses investments on  $q$  and capital cost. Within the Euler investment equation approach the solved first order condition for investment is estimated using a dynamic model specification. The use of panel data requires the Generalised Method of Moments (GMM) (ARELLANO and BOND 1991; BLUNDELL and BOND 1998).

In order to account for capital market frictions the models developed under the assumption of perfect capital markets are extended by proxies for the availability of internal funds, e.g., the cash flow. The empirical significance of those is tested to give evidence on imperfect capital markets. Therefore, the sample must be partitioned referring to the probability that a firm is affected by informational shortcomings. A major problem in empirical work is the choice of the sample separation criterion (SCHIANTARELLI 1995). WHITED (1992) partitions the sample based on a measure of financial distress of the firms. BOND and MEGHIR (1994) present a direct test of the empirical impacts of the hierarchy of the finance model specification for UK panel data. Alternatively, GILCHRIST and

HIMMELBERG (1995) extend the standard  $q$  model using a vector autoregressive model (VAR). This enables to estimate the shadow value of capital  $q$  and the investment rate simultaneously. The cash flow, which proxies internal financial sources, is confirmed as an investment fundamental<sup>1</sup>. LAGERQVIST and OLSON (2001) provide an empirical Euler equation for farm investments. Thereby a second Euler equation for finance is also estimated. The results endorse agency problems and asymmetric information affecting farms' capital structure.

CABALLERO (1997) gives an overview about empirical investment models considering lumpy and irreversible investments. For instance ABEL and EBERLY (2002) provide empirical evidence on asymmetric and non-linear paths of investments. NILSEN and SCHIANTARELLI (2003) use Norwegian firm level panel data to explain non-smooth investment behaviour and take non-convex adjustment costs into account. The results state a significant probability of periods of high investments. VERICK et al. (2004) assume that the firm faces two decisions – investment in replacement and investment in the expansion of the capital stock. The used German plant level data set allows identifying both regimes facing different types of adjustment costs. Table 1 summarizes further empirical investment studies.

The empirical applications so far emphasise how investment is affected by imperfect capital markets and the presence of irreversibility. However, to our knowledge empirical applications do not provide any 'bridging' application to irreversible investment in an imperfect capital market. In the following section we present our suggestion to consider both issues while explaining investment behaviour at the firm level.

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<sup>1</sup> It should be noted that ERICKSON and WHITED (2000) discuss possible measurement problems of  $q$ , which might lead to significant variables that are often used to proxy imperfect capital markets.

**Table 1: Empirical Studies about the Relation of Investments and Imperfect Capital Markets**

Authors (Year)	Approach	Econometric Model Specification	Endogenous Variable	Exogenous Variables	Sector/Country/Data	Estimation	Hypotheses/Results
FAZZARI and ATHEY (1987)	Capital Asset Pricing Model, Credit Rationing Theory	Static Regression	Investment rate	Sales, CF <sup>1)</sup> , interest payments and depreciation	Industry USA Panel data (1975-1985)	GLS <sup>2)</sup>	Significant impact of financing constraints on the firm investment
BOND and MEGHIR (1994)	Euler Investment Equation, Pecking Order Theory	Dynamic Regression	Investment rate	Lagged investment rate, output-capital ratio, CF-capital ratio, leverage	Industry UK Panel data (1968-1986)	GMM <sup>3)</sup>	Positive relationship between investment and availability of internal funds (CF)
CARTER and OLINTO (2003)	Credit Rationing, Property Rights Theory	Switching Regression	Capital stock	Farm size, leased and own land; dummies for farm types	Agriculture Paraguay Panel data (1991-1994)	OLS-FD <sup>4)</sup>	Significant positive impact of the property rights reform on the investment activity of large farms
GILCHRIST and HIMMELBERG (1995)	$q$ Model	VAR <sup>5)</sup>	Investment rate	Tobin's $q$ , marginal $q$ , CF	Capital market USA Compustat Data (1979-1989)	GMM <sup>3)</sup>	Contrary to marginal $q$ , Tobin's $q$ overestimates the CF sensitivity of investment decisions, in particular for financially constrained firms
BIERLEN and FEATHERSTONE (1998)	$q$ Model	VAR <sup>5)</sup>	Investment rate	Marginal $q$ , CF	Agriculture USA Panel data (1976-1992)	GMM <sup>3)</sup>	Leverage ratio is the most important determinant of credit constraints; capital stock and other farm characteristics are less significant factors
HU and SCHIANTARELLI (1998)	$q$ Model	Switching Regression	Investment rate	Market value-capital ratio, CF-capital ratio	Industry USA Panel data (1978-1987)	ML <sup>6)</sup>	Different impact of capital market imperfections on the firms' investment behaviour, depending on firm characteristics and macroeconomic environment
BARRY et al. (2000)	$q$ Model, Pecking Order Theory	VAR <sup>5)</sup>	Short and long term debt, leasing payments, investment	Marginal $q$ , CF, lagged debt and leasing payments	Agriculture USA Panel data (1987-1994)	GMM <sup>3)</sup>	Significant positive relationship between CF and investment; long-term adjustment of the capital structure
ERICKSON and WHITED (2000)	$q$ Model	Static Regression	Investment rate	Marginal $q$ , CF	Industry USA Panel data (1992-1995)	OLS <sup>7)</sup> GMM <sup>3)</sup>	Contrary to $q$ , CF does not explain investment behaviour of either financially constrained or unconstrained firms
GOMES (2001)	$q$ Model	Static Regression	Investment rate	Tobin's $q$ , CF	Industry USA Panel data (1979-1988)	OLS <sup>7)</sup>	Overestimated CF sensitivity of investment because of the $q$ measurement errors and identification problems

**Table 1: Empirical Studies about the Relation of Investments and Imperfect Capital Markets (Continued)**

Authors (Year)	Approach	Econometric Model Specification	Endogenous Variable	Exogenous Variables	Sector/Country/Data	Estimation	Hypotheses/Results
LAGERKVIST and OLSON (2001)	Euler Investment Equation, Agency Theory	Dynamic Regression	Investment rate	Leverage	Agriculture USA Panel data (1989-1998)	GMM <sup>3)</sup>	Agency problems and informational asymmetries influence either capital structure and capital accumulation
BENJAMIN and PHIMISTER (2002)	$q$ Model, Euler Investment Equation, Pecking Order Theory	VAR <sup>3)</sup> , Dynamic Regression	Investment rate	Output, CF, marginal $q$ , equity	Agriculture UK and France Panel data (1987-1992)	GMM <sup>3)</sup>	Different sensitivity of investment to CF according to the country and investment type
LIZAL and SVEJNAR (2002)	Credit Rationing Theory, Soft Budget Constraints Theory	Static Regression	Investment rate	Profit-capital ratio, output-capital-ratio	Industry Czech Republic Panel data (1992-1998)	OLS <sup>7)</sup>	Enterprises aim at profit maximisation; however, large firms operate under soft budget constraints, whilst small firms are often credit rationed
HANOUSEK and FILER (2004)	Credit Rationing Theory, Soft Budget Constraints Theory	Static Regression	Investment rate	Profit-capital ratio, output-capital ratio	Industry Czech Republic Panel data (1993-1998)	IV <sup>8)</sup> OLS <sup>7)</sup>	Positive relationship between profit and investment indicates no credit rationing but the better investment opportunities; SBC are firm specific
PAVEL et al. (2004)	Credit Rationing Theory	Switching Regression	Investment rate	Marginal $q$ , CF	Industry Ukraine Panel data (1993-1998)	ML <sup>6)</sup>	Credit rationing hypothesis is verified; financially constrained firms are smaller and have higher capital productivity than unconstrained firms
RIZOV (2004)	Euler Investment Equation, Credit Rationing Theory, Soft Budget Constraints Theory	Dynamic Regression	Investment rate	Lagged investment rate, CF-capital ratio, output-capital ratio, leverage	Industry Romania Panel data (1995-1999)	GMM <sup>3)</sup>	The SBC hypothesis confirmed; firms with unconstrained credit access reveal a weaker CF sensitivity of investment decisions

<sup>1)</sup> CF = Cash Flow

<sup>2)</sup> GLS = Generalized Least Squares

<sup>3)</sup> GMM = Generalized Method of Moments

<sup>4)</sup> OLS-FD = Ordinary Least Squares with First Differences

<sup>5)</sup> VAR = Vector of Autoregressive Equations

<sup>6)</sup> ML = Maximum Likelihood

<sup>7)</sup> OLS = Ordinary Least Squares

<sup>8)</sup> IV = Instrumental Variables Estimator

Source: Own presentation



### 3 Methodological approach: A $q$ Model for Irreversible Investments in Imperfect Capital Markets

The dynamic and stochastic adjustment cost model in line with ABEL and EBERLY (1994) is extended in order to account for additional transaction cost induced by imperfect capital markets. We present first the theoretical model and then the empirical (econometric) model specification.

#### 3.1 Theoretical Model

The partial equilibrium model comprises production and investments for a representative firm<sup>2</sup>. The relationship between product price  $p$  and quantity  $y$  in continuous time  $t$  is described by an iso-elastic demand function:

$$(1) \quad p(t) = y(t)^{(1-\psi)/\psi} \cdot X(t), \text{ where } \psi \geq 1.$$

$\psi$  refers to the price elasticity of demand and  $X$  is a stochastic demand parameter which exhibits Geometric Brownian Motion (GBM)

$$(2) \quad dX = \mu \cdot X \cdot dt + \sigma \cdot X \cdot dz,$$

where  $\mu$  denotes the drift rate,  $\sigma$  the standard deviation and  $dz$  is a Wiener increment. The output  $y$  follows a Cobb-Douglas production function

$$(3) \quad y = A \cdot L^\alpha \cdot K^{1-\alpha},$$

where  $A$  denotes a technology parameter,  $L$  refers to labour and  $K$  refers to capital.  $\alpha$  describes the production elasticity of labour whereas labour input can be adjusted without additional costs. The profit function is derived using the necessary conditions for profit-maximising labour input. Operating profit  $\pi$  is defined as

$$(4) \quad \pi = h \cdot X^{\eta_x} \cdot K^{\eta_k},$$

where  $h > 0^3$ .  $h \cdot X^{\eta_x}$  refers to the marginal revenue product of capital at time  $t$ ,  $\eta_x = \frac{1}{1-\alpha} > 1$  and  $\eta_k = 1$ .

The adjustment cost function of capital input,  $C(I)$ , has three parts, one for each activity: investment, disinvestment and inaction. The respective parts consist of three terms: the fixed costs  $a$ , the capital costs  $b_1$  and  $b_2$  which are linear in  $I(t)$  and the internal adjustment costs  $\gamma_1$  and  $\gamma_2$  which are quadratic in  $I(t)$  and strictly convex (BÖHM et al. 1999).

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<sup>2</sup> We suppress the time variable  $t$  where possible.

<sup>3</sup>  $h = (1-\alpha) \cdot \left(\frac{\alpha}{\omega}\right)^{\alpha/(1-\alpha)} \cdot A^{1/(1-\alpha)}$  (ABEL and EBERLY 1994).

$$(5) \quad C(I) = \begin{cases} a + b_1 \cdot I + \gamma_1 \cdot I^2 & \text{if } I > 0 \\ 0 & \text{if } I = 0 \\ a + b_2 \cdot I + \gamma_2 \cdot I^2 & \text{if } I < 0, \end{cases}$$

where  $b_1$  denotes the cost for capital when investing and  $b_2$  denotes the respective cost when disinvesting. It is essential that  $b_1 \geq b_2 \geq 0$  and  $\gamma_1, \gamma_2 \geq 0$ . If  $b_1 > b_2$  and  $a \geq 0$  hold, then the investment costs are sunken and thus the investment decision is characterised by irreversibility. This induces the range of inaction.

In general, the objective of the representative firm is the maximisation of the present value of net income depending upon the current capital stock  $K_0$  and the initial stochastic demand variable  $X_0$ . Therefore we define the value-function  $V$  as the result of the maximisation.

$$(6) \quad V(K_0, X_0) = \max_I \int_0^{\infty} E \left[ h \cdot X^{\eta_x} \cdot K^{\eta_k} - C(I) \right] \cdot e^{-r \cdot t} dt,$$

where  $r$  denotes the discount rate. The maximisation is subject to the evolvement of the capital stock over time:

$$(7) \quad dK = (I - \delta \cdot K) dt,$$

where  $\delta$  describes the depreciation rate. In accordance with the dynamic programming approach the optimal path of investment follows the Bellman equation.

$$(8) \quad r \cdot V(K, X) = \max_I \left\{ h \cdot X^{\eta_x} \cdot K^{\eta_k} - C(I) + \frac{E[dV]}{dt} \right\}.$$

Equation (8) requires the return  $r \cdot V$  to equal the sum of profit  $h \cdot X^{\eta_x} \cdot K^{\eta_k}$ , adjustment costs for capital stock,  $-C(I)$ , and the expected capital gain  $E[dV]/dt$ . Applying Ito's Lemma for solving  $dV$ , taking into account  $E[z] = 0$  and using equation (2) leads to the following expression for  $E[dV]$ :

$$(9) \quad \frac{E[dV]}{dt} = \mu \cdot X \cdot \frac{\partial V}{\partial X} + \frac{1}{2} \cdot \sigma^2 \cdot X^2 \cdot \frac{\partial^2 V}{\partial X^2} + (I - \delta \cdot K_0) \cdot \frac{\partial V}{\partial K}.$$

Inserting equation (9) in (8) gives:

$$(10) \quad r \cdot V = \max_I \left\{ h \cdot X^{\eta_x} \cdot K^{\eta_k} - C(I) + \mu \cdot X \cdot \frac{\partial V}{\partial X} + \frac{1}{2} \cdot \sigma^2 \cdot X^2 \cdot \frac{\partial^2 V}{\partial X^2} + (I - \delta \cdot K_0) \cdot \frac{\partial V}{\partial K} \right\}.$$

We now define  $q = \partial V / \partial K$  as the marginal valuation of a unit of installed capital. The optimal path of investment solves the term:

$$(11) \quad \max_I \{-C(I) + I \cdot q\}.$$

The necessary conditions are:

$$(12a) \quad -(b_1 + 2\gamma_1 \cdot I) + q = 0$$

$$(12b) \quad -(b_2 + 2\gamma_2 \cdot I) + q = 0.$$

Solving the equations (12a) and (12b) gives the optimal investment ( $I_1$ ) and disinvestment ( $I_2$ ) volumes. These are functions of  $q$ , the price of capital, and the slope parameters of the adjustment cost function:

$$(13a) \quad I_1 = -\frac{b_1}{2\gamma_1} + \frac{1}{2\gamma_1} \cdot q$$

$$(13b) \quad I_2 = -\frac{b_2}{2\gamma_2} + \frac{1}{2\gamma_2} \cdot q.$$

Since the maximand in equation (11) is equal to zero when the firm does neither invest nor disinvest  $I_1$  and  $I_2$  are only optimal when  $-C(I_{1/2}) + I_{1/2} \cdot q \geq 0$  holds. The roots of the terms  $-C(I_1) + I_1 \cdot q = 0$  and  $-C(I_2) + I_2 \cdot q = 0$ , respectively, are:

$$(14a) \quad q_1 = b_1 + 2 \cdot \sqrt{\gamma_1 \cdot a}$$

$$(14b) \quad q_2 = b_2 - 2 \cdot \sqrt{\gamma_2 \cdot a}.$$

If  $q$  lies between the lower threshold,  $q_2$ , and the upper threshold,  $q_1$ , neither investments nor disinvestments are optimal. This is also known as the range of inaction. The optimal (dis)investment strategy is characterised by three regimes:

$$(15) \quad \begin{aligned} I &= I_1 & \text{if } q > q_1 \\ I &= 0 & \text{if } q_2 \leq q \leq q_1 \\ I &= I_2 & \text{if } q < q_2. \end{aligned}$$

Imperfect capital markets occur in different ways (CHATELAIN 2002)

- In limited liability companies different costs for retained profits and acquired venture capital arise because of tax schemes or transaction costs.
- Bankruptcy risks and monitoring expenses induce transaction costs leading to higher costs for debt capital than for equity capital.
- Firms might also be credit constrained for the same reasons.

Literature offers several approaches to model the impacts of imperfect capital markets. A common way of modelling is to define a financial variable (e.g., liquidity or debt capital stock) as an additional state or control variable. This is accompanied by an additional

constraint accounting for the upper limit of bank loans or new indebtedness, see for instance RIZOV (2004) or WHITED and WU (2006). Alternatively, LAGERQVIST and OLSEN (2001) assume that additional adjustment costs arise when the borrowed capital stock changes. We refer to the latter suggestion and implement the additional transaction costs in the context of imperfect capital markets into the adjustment cost function. The main advantage is that the dimensions of the model are not increased. In what follows we assume that the adjustment costs depend additionally on the internal financial power defined as the relation of the cash flow ( $CF$ ) to investments. To be precise, adjustment costs now depend not only on investments but also on the firms' cash flow,

$$(16) \quad C(I, CF) = \begin{cases} a + b_1 \cdot I + \gamma_1 \cdot I^2 + d_1 \cdot \frac{I}{CF} & \text{if } I > 0 \\ 0 & \text{if } I = 0 \\ a + b_2 \cdot I + \gamma_2 \cdot I^2 + d_2 \cdot \frac{I}{CF} & \text{if } I < 0. \end{cases}$$

Financial ability now affects the range of inaction and also the optimal investment volume if capital markets are imperfect. The financial ability widens the range of inaction, such that the larger (smaller) the cash flow, the weaker (stronger) the internal financing is and the smaller (larger) the increase of the range of inaction is. The thresholds are defined as functions of the cash flow and are no longer constant,

$$(17a) \quad q_1 = b_1 + 2 \cdot \sqrt{\gamma_1 \cdot a} + \frac{d_1}{CF}$$

$$(17b) \quad q_2 = b_2 - 2 \cdot \sqrt{\gamma_2 \cdot a} + \frac{d_2}{CF}.$$

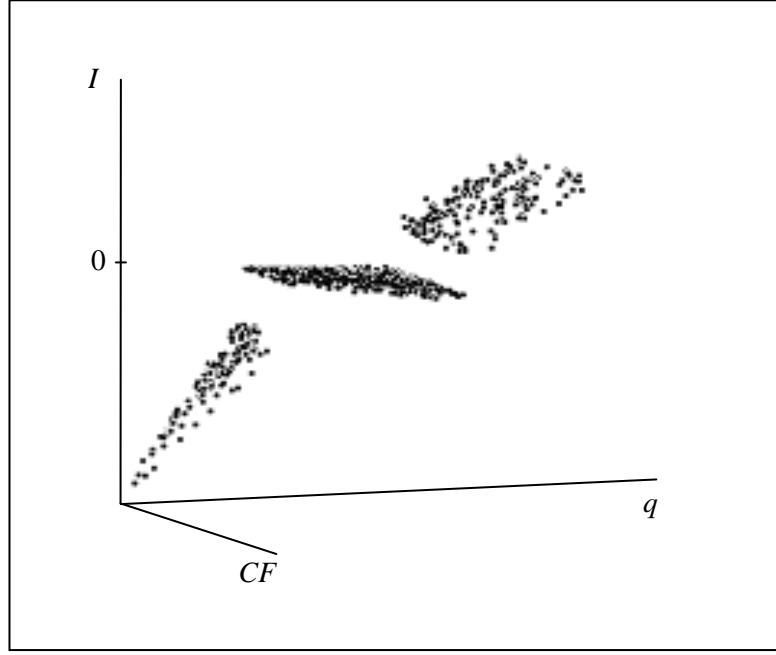
Moreover, the cash flow indirectly affects the optimal (dis)investment volume due to the modified adjustment cost function. Given an active regime, the optimal investment volume depends on the price for capital,  $q$  and cash flow:

$$(18a) \quad I_1 = -\frac{b_1}{2\gamma_1} + \frac{1}{2\gamma_1} \cdot q - \frac{d_1}{2\gamma_1} \cdot \frac{1}{CF}$$

$$(18b) \quad I_2 = -\frac{b_2}{2\gamma_2} + \frac{1}{2\gamma_2} \cdot q - \frac{d_2}{2\gamma_2} \cdot \frac{1}{CF}.$$

The extended model describes the optimal investment strategy and takes into account irreversible investment while the firm acts in an imperfect capital market. Figure 1 illustrates the relation between (dis)investment  $I$ , the shadow value of capital  $q$  and the cash flow  $CF$  derived from a simulated data sample.

**Figure 1: Representation of the relation of  $q$ , cash flow and (dis)investments**



### 3.2 Econometric Model Specification

Figure 1 apparently implies the use of a non-linear econometric model to explain the relationship of investment,  $q$  and the cash flow appropriately. In particular, we refer to a generalised double censored Tobit specification (CAMERON and TRIVEDI 2005; DI IORIO and FACHIN 2006) or two-sided generalized Tobit model. According to MADDALA (1983) the latent variables are defined as

$$(19a) \quad I_{1it}^* = -\frac{b_1}{2\gamma_1} + \frac{1}{2\gamma_1} \cdot q_{it} - \frac{d_1}{2\gamma_1} \cdot \frac{1}{CF_{it}} + \varepsilon_{1it}$$

$$(19b) \quad I_{2it}^* = -\frac{b_2}{2\gamma_2} + \frac{1}{2\gamma_2} \cdot q_{it} - \frac{d_2}{2\gamma_2} \cdot \frac{1}{CF_{it}} + \varepsilon_{2it},$$

where  $i$  indexes firms ( $i=1, \dots, N$ ) and  $t$  indexes time ( $t=1, \dots, T$ );  $\varepsilon_{1it}$  and  $\varepsilon_{2it}$  are two normally independently distributed error terms (*n.i.d.*) with variances  $\sigma_{\varepsilon_1}^2$  and  $\sigma_{\varepsilon_2}^2$ , respectively. The error terms reflect idiosyncratic shocks which are not observable to the econometrician and may also include some measurement errors. The latent variables  $I_{1it}^*$  and  $I_{2it}^*$  describe a target investment volume in order to deliver the desired amount of output under standard operating conditions. However, the variable of interest,  $I_{it}$ , is observable. As described in the previous section the firm invests or disinvests if  $q_{it}$  passes the respective thresholds  $q_{1it}$  and  $q_{2it}$ . Hence, observed investment can be modelled as:

$$(20) \quad \begin{aligned} I_{it} &= I_{1it}^* && \text{if } q_{it} - q_{1it} > 0 \\ I_{it} &= 0 && \text{if } q_{2it} - q_{it} \geq 0 \geq q_{1it} - q_{it} \\ I_{it} &= I_{2it}^* && \text{if } q_{it} - q_{2it} < 0. \end{aligned}$$

The stochastic representation of the thresholds  $q_1$  and  $q_2$  is

$$(21a) \quad q_{1it} = b_1 + 2 \cdot \sqrt{\gamma_1 \cdot a} + \frac{d_1}{CF_{it}} + v_{1it}$$

$$(21b) \quad q_{2it} = b_2 - 2 \cdot \sqrt{\gamma_2 \cdot a} + \frac{d_2}{CF_{it}} + v_{2it},$$

where  $v_{1it}$  and  $v_{2it}$  are two independent standard normally distributed error terms with zero mean. These error terms account for idiosyncratic shocks that are not observable to the econometrician. Accordingly, investment occurs as

$$(22a) \quad I_{it} = I_{1it}^* = -\frac{b_1}{2\gamma_1} + \frac{1}{2\gamma_1} \cdot q_{it} - \frac{d_1}{2\gamma_1} \cdot \frac{1}{CF_{it}} + \varepsilon_{1it},$$

when:

$$(22b) \quad (-b_1 - 2 \cdot \sqrt{\gamma_1 \cdot a}) + q_{it} - \frac{d_1}{CF_{it}} - v_{1it} > 0.$$

Disinvestment occurs as

$$(23a) \quad I_{it} = I_{2it}^* = -\frac{b_2}{2\gamma_2} + \frac{1}{2\gamma_2} \cdot q_{it} - \frac{d_2}{2\gamma_2} \cdot \frac{1}{CF_{it}} + \varepsilon_{2it},$$

when

$$(23b) \quad (-b_2 + 2 \cdot \sqrt{\gamma_2 \cdot a}) + q_{it} - \frac{d_2}{CF_{it}} - v_{2it} < 0.$$

We assume that the error terms  $\varepsilon_{1/2it}$  and  $v_{1/2it}$  are uncorrelated. This restrictive assumption allows specifying the model as a double hurdle model introduced by CRAGG (1971). This is an alternative specification of the Tobit model for corner solutions (WOOLDRIDGE 2002, p. 538). The assumption of uncorrelated error terms enables to estimate the model in two parts. Furthermore, we abstract from unobserved heterogeneity to simplify the estimation<sup>4</sup>. In the first part we estimate an ordered probit model to obtain the probabilities of being in one of the regimes. The results allow to identify the thresholds  $q_{1it}$  and  $q_{2it}$ . The probability of being in the investment regime is given by:

$$(24a) \quad \Pr(q_{it} > q_{1it}) = \Pr(q_{it} - q_{1it} > 0) = \Phi_{v_{1it}}(q_{it} - q_{1it}).$$

Accordingly, the probability of being in the disinvestment regime refers to:

$$(24b) \quad \Pr(q_{it} < q_{2it}) = \Pr(q_{it} - q_{2it} < 0) = 1 - \Phi_{v_{2it}}(q_{it} - q_{2it}).$$

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<sup>4</sup> Possible error term structures and the consideration of more complex estimation procedure as well as the panel data specifications according to unobserved heterogeneity are left for future research.

and finally, the probability of inactivity is:

$$(24c) \quad \Pr(q_{2it} \leq q_{it} \leq q_{1it}) = \Phi_{v_{1it}}(q_{it} - q_{1it}) - \Phi_{v_{2it}}(q_{it} - q_{2it}).$$

Thus, we define the likelihood function for the ordered probit model:

$$(25) \quad \begin{aligned} L(\gamma_0^+, \gamma_0^-, \gamma_1^+, \gamma_1^-, \gamma_2^+, \gamma_2^- | I_{it}, q_{it}, CF_{it}) = \\ \prod_1 \Phi \left[ \left( \gamma_0^+ + \gamma_1^+ \cdot q_{it} + \gamma_2^+ \cdot CF_{it}^{-1} \right) \right] \times \\ \prod_0 \left( \Phi \left[ \left( \gamma_0^+ + \gamma_1^+ \cdot q_{it} + \gamma_2^+ \cdot CF_{it}^{-1} \right) \right] - \Phi \left[ \left( \gamma_0^- + \gamma_1^- \cdot q_{it} + \gamma_2^- \cdot CF_{it}^{-1} \right) \right] \right) \times \\ \prod_{-1} \left( 1 - \Phi \left[ \left( \gamma_0^- + \gamma_1^- \cdot q_{it} + \gamma_2^- \cdot CF_{it}^{-1} \right) \right] \right). \end{aligned}$$

The parameters are defined as follows:  $c_0^+ = -\frac{b_1}{2\gamma_1}$ ,  $c_0^- = -\frac{b_2}{2\gamma_2}$ ,  $\gamma_0^+ = (-b_1 - 2 \cdot \sqrt{\gamma_1 \cdot a})$ ,  
 $\gamma_0^- = (-b_2 + 2 \cdot \sqrt{\gamma_2 \cdot a})$ ,  $c_1^+ = \frac{1}{2\gamma_1}$ ,  $c_1^- = \frac{1}{2\gamma_2}$ ,  $c_2^+ = -\frac{d_1}{2\gamma_1}$ ,  $c_2^- = -\frac{d_2}{2\gamma_2}$ ,  $\gamma_1^+ = \gamma_1^- = 1$ ,  
 $\gamma_2^+ = -d_1$ ,  $\gamma_2^- = -d_2$ .

We use a state variable to indicate whether investment, disinvestment or inaction is observed. Accordingly,  $\prod_1$  and  $\prod_{-1}$  include observations of (dis)investments and  $\prod_0$  includes observations referring to the range of inaction.

In the second part the investment and disinvestment equations (22a) and (23a) are estimated separately by ordinary least squares (OLS) using the respective observed data in the regimes. Because of the uncorrelated error terms there is no need to estimate the investment and disinvestment equation conditional on being in the regime.

Our aim is to quantify the bias which is likely when using simple linear models without consideration of the range of inaction in this context. Therefore we construct a simplified linear econometric model for which the generalised Tobit model serves as a benchmark:

$$(26) \quad I_{it}^b = c_0 + c_1 \cdot q_{it} + c_2 \cdot \frac{1}{CF_{it}} + u_{it}, \text{ where } u \sim i.i.d.(0, \sigma_u^2).$$

The superscript  $b$  denotes benchmark. This general kind of model can be found in BENJAMIN and PHIMISTER (2002), BIERLEN and FEATHERSTONE (1998) or RIZOV (2004). To avoid any misunderstandings the used investment models in these publications are more complex than the defined benchmark model, for instance the models are still linear but also dynamic. If imperfect capital markets and irreversibility coexist we conjecture that a disregard of irreversibility and uncertainty within the estimation like in equation (26) leads to biased results. This may in particular cause problems when the aim is to find evidence on imperfect capital markets.

## 4 Simulation Experiments

We conduct Monte Carlo simulations to prove the above mentioned concerns about a possible bias. Thereby the drawings and the estimations are repeated 1 000 times. We use the mean of the estimated coefficient and the respective standard error to obtain the final results. Simulation runs are preferred towards empirical data in order to control for the complexity of the data generating process and the parameters are known. This allows finding out about the behaviour of both models. For simplification reasons and to avoid biases we abstract from firm individual specific and time effects which are very likely in empirical panel data. In what follows first the scenarios and the data simulation are presented (subsection 4.1) and afterwards the simulation results are shown (subsection 4.2).

### 4.1 Data and Scenarios

Panel data at the firm level are generated based on the theoretical investment model described in section three<sup>5</sup>. Table 2 explains briefly the structure of the scenarios, which differ by the presence of irreversibility and the assumption of a perfect or imperfect capital market. Furthermore, the detailed parameter assumptions can be found in table 2.

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<sup>5</sup> For the simulation and estimation we used STATA 10.



**Table 2: Parameter Assumptions in the Simulation-Based Experiments**

Scenario Assumptions		<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>
Capital Market		imperfect	perfect	perfect
Range of inaction induced by irreversibility		yes	yes	no
Symbol	Description			
$r$	Discount rate	5%	5%	5%
$\delta$	Depreciation rate	5%	5%	5%
$\mu$	Drift rate of the demand parameter	0%	0%	0%
$\sigma$	Standard deviation of the demand parameter	10%	10%	10%
$\eta_X$	Represents returns to scale and the competition parameter of demand	1.001	1.001	1.001
$\eta_K$	Represents returns to scale and the competition parameter of capital	1	1	1
$a$	Fixed costs of investment vs. disinvestment independent of the current amount	2	2	0
$b_1$	Price per unit of capital to be invested	9.5	9.5	8
$\gamma_1$	Adjustment cost parameter in the case of investment	0.5	0.5	0.5
$d_1$	Weighting coefficient of the inverse internal financial power in the case of investment	10	0	0
$b_2$	Price per unit of capital to be disinvested	8	8	8
$\gamma_2$	Adjustment cost parameter in the case of disinvestment	0.1	0.1	0.5
$d_2$	Weighting coefficient of the inverse internal financial power in the case of disinvestment	-10	0	0

For all scenarios we simulate  $N = 5\,000$  farms over  $T = 20$  years. In detail we proceed as follows.

- Profit  $\pi_{it}$  of farm  $i$  at time  $t$  follows a discrete time version of equation (4). The farm individual initial capital stock is generated by a random number. Based on this initialisation the further evolution of the capital stock follows (7). The depreciation rate  $\delta$  is assumed to be 5%. According to equation (2) the stochastic demand parameter  $X_{it}$  is modelled as GBM without Drift (i.e.,  $\mu = 0\%$ ) but with standard deviation  $\sigma$  of 10%. For simplification the parameter  $h$  is modelled as a positive constant.
- The adjustment costs for the capital stock  $C(I_{it}, CF_{it})$  are modelled referring to equation (16).
- The cash flow,  $CF_{it}$ , is modelled as the sum of profit and depreciation, and is ended with a uniformly distributed error term  $e_{it}$  between 0 and 0.3:

$$(27) \quad CF_{it} = (\pi_{it} + \delta \cdot K_{it}) \cdot e_{it}.$$

- The thresholds  $q_{1it}$  and  $q_{2it}$  follow equations (14a) and (14b). The data generating process of the optimal path of investment,  $I_{it}$ , is described in equation (15). We use (18a) for investments and (18b) for disinvestments ( $I_2$ ).
- Under the assumption of constant returns to scale and perfect competition the differential equation in (10) and the value function (6) become linear in  $K$ . This allows to derive an analytical solution for  $q_{it}$  (ABEL und EBERLY 1994):

$$(28) \quad q_{it} = \frac{h_{it} \cdot X_{it}^{\eta_X}}{(r + \delta - \eta_X \cdot \mu - \frac{1}{2} \cdot \sigma^2 \cdot \eta_X (\eta_X - 1))},$$

where  $r$  is the riskless interest rate and assumed to be 5 %. Regarding (27) it becomes obvious that  $q_{it}$  is determined by the parameters of the stochastic part of demand function,  $X_{it}$ : the drift rate,  $\mu$ , the standard deviation,  $\sigma$ , as well as the competition parameter,  $\eta_X$ .

- The relationship between investment, cash flow and  $q$  is overlaid by normally distributed shocks  $\varepsilon_{1it}$  and  $\varepsilon_{2it}$  with a variance of one half according to equations (24a) and (24b). Furthermore, the thresholds  $q_{1it}$  and  $q_{2it}$  are overlaid by standard normally distributed error terms  $v_{1it}$  and  $v_{2it}$  referring to equations (21a) and (21b)<sup>6</sup>.

We simulate and estimate both models for three different scenarios (cf. Table 2). In the *first scenario* we regard investment behaviour in an imperfect capital market with irreversibility implying differing investment and disinvestment functions and a present range of inaction. Additionally, the cash flow affects the decision of whether to invest or not and the decision of how much to invest. Therefore a positive value for parameters  $d_1$  and  $d_2$  is chosen. In the *second scenario*, we look at sunk costs caused by irreversibility under conditions of a perfect capital market. This implies that the cash flow does not affect investments or disinvestments but a range of inactivity exists. In both *scenarios*, *one* and *two*, we explicitly model sunk costs in order to ensure a range of inaction. This is achieved by choosing different parameters for the costs or revenues per unit capital for investments and disinvestments such that  $b_1 > b_2 > 0$  and fixed costs are assumed, i.e.  $a \neq 0$ . The slope parameters  $\gamma_1$  and  $\gamma_2$  of the adjustment cost function are unequal inducing different speeds of adjustment of the capital stock. In the *third scenario* a perfect capital market without range of inaction is assumed meaning unequal capital cost for investments and disinvestments, no fixed costs and there is no cash flow effect, neither on the decision to invest/disinvest nor on the investment/disinvestment volume. Thereby only a random number is observed in the inactivity regime, e.g., firms that have already reached the desired capital stock.

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<sup>6</sup> It should be noted that the results are sensitive to the specification of the error terms.

## 4.2 Results

In what follows we present the results of the simulation based experiments. For each scenario we simulate the data and estimate the generalised Tobit model as well as the benchmark model with 1 000 replications. The results of the first part, the ordered probit model, have been fully satisfying for all scenarios. We aim at identifying the bias when the range of inaction is ignored in investment regressions and thus we disclaim presenting the results of the ordered probit model.

In scenario 1, a range of inaction and an impact of the cash flow are modelled representing the most realistic case. In table 4 the averages of the 1 000 replications of the estimates and the respective standard errors as well as the mean R-squares for both models are given. The results show that both models give the correct estimates. However, regarding the goodness of fit measure, the results of the benchmark model are less satisfactory. This implies a weaker fit when disregarding the range of inaction.

**Table 4: Results of Scenario 1 (Irreversibility of Investments under Imperfect Capital Markets)**

		Benchmark Model		Tobit Model (2nd part)		<i>pre-setting</i>
		estimate	standard error	estimate	standard error	
$c_0^+$	<i>constant</i>	-27.0698	(0.4592)***	-9.4996	(0.0150)***	-9.50
$c_0^-$				-39.9851	(0.0137)***	-40.00
$c_1^+$	<i>q</i>	2.5035	(0.2338)***	1.0000	(0.0010)***	1.00
$c_1^-$				4.9972	(0.0019)***	5.00
$c_2^+$	<i>cash flow</i>	-42.4859	(0.0252)***	-15.0000	(0.0006)***	-15.00
$c_2^-$				-50.0000	(0.0001)***	-50.00
$R^2$		92.95%		99.99 % <sup>+</sup> / 99.21 % <sup>-</sup>		--

Note: Single (\*), double (\*\*) and triple (\*\*\*) asterisks denote significant at 10%, 5% and 1%, respectively.

Source: Own calculations based on 1 000 replications.

In this context it is interesting to find out about the performance of the benchmark model when capital markets are perfect. Accordingly, in scenario 2 an explicit range of inaction is modelled but without any cash flow impacts. The results are shown in table 5.

**Table 5: Results Scenario 2 (Irreversibility of investments under perfect capital markets)**

		Benchmark Model		Tobit Model (2nd part)		<i>pre-setting</i>
		estimate	standard error	estimate	standard error	
$c_0^+$	<i>constant</i>	-13.9324	(0.0302)***	-9.5001	(0.0142)***	-9.50
$c_0^-$				-39.9415	(0.0219)***	-40.00
$c_1^+$	<i>q</i>	1.3513	(0.0029)***	1.0000	(0.0010)***	1.00
$c_1^-$				4.9892	(0.0036)***	5.00
$c_2^+$	<i>cash flow</i>	-0.0012	(0.0006)**	-0.0001	(0.0013)	0.00
$c_2^-$				0.0000	(0.0002)	0.00
$R^2$	69.23%		97.49 % <sup>+</sup> / 99.21 % <sup>-</sup>		--	

Note: Single (\*), double (\*\*), and triple (\*\*\*) asterisks denote significant at 10%, 5% and 1%, respectively.

Source: Own calculations based on 1 000 replications.

Even though a cash flow effect is not modelled the benchmark model shows a significant parameter estimate. The coefficient is very low; however, the resulting conclusion would indicate capital market frictions. Comparing the results with the second stage Tobit regressions, the goodness of fit in the benchmark model is comparable low, particularly in the context of simulated data.

In scenario 3, the impact of the cash flow is zero and the range of inaction is not modelled. However, 12.57 % of the observations are still within the inaction regime which is induced by the random error terms. This could be firms that have already reached their desired capital stock. Table 6 depicts the results showing correct estimates for both models. It should be noted, for the disinvestment regime the Tobit model delivers estimates which slightly differ from the pre-setting.

**Table 6: Results Scenario 3 (Full reversibility of investments under perfect capital markets)**

		Benchmark Model		Tobit Model (2nd part)		<i>pre-setting</i>
		estimate	standard error	estimate	standard error	
$c_0^+$	<i>constant</i>	-8.0986	(0.0059)***	-8.0000	(0.0080)***	-8.00
$c_0^-$				-7.5030	(0.0223)***	-8.00
$c_1^+$	<i>q</i>	1.0053	(0.0006)***	1.0000	(0.0007)***	1.00
$c_1^-$				0.8999	(0.0034)***	1.00
$c_2^+$	<i>cash flow</i>	0.0000	(0.0003)	0.0000	(0.0005)	0.00
$c_2^-$				0.0000	(0.0007)	0.00
$R^2$	97.17%		96.99 % <sup>+</sup> / 76.96 % <sup>-</sup>		--	

Note: Single (\*), double (\*\*), and triple (\*\*\*) asterisks denote significant at 10%, 5% and 1%, respectively.

Source: Own calculations based on 1 000 replications.

Summarizing, under conditions of a perfect capital market, the results of simpler linear models show a significant cash flow parameter if the range of inaction induced by irreversibility is not considered. Irreversible investments inducing a range of inaction are

falsely interpreted as capital market imperfections. Generally, it can be concluded that the cash flow accounts also for the irreversible investment decision beyond financial constraints. In empirical applications this bias may even be higher as it is overlaid by missing information in poor proxy variables for  $q$  (ERICKSON and WHITED 2000).

## 5 Conclusions and Outlook

In this paper, we identify the bias when irreversibility in imperfect capital markets is not adequately considered by investment models. Therefore we define an investment model which explicitly comprises capital market imperfections using a proxy for internal finance, and accounts for coexistent irreversibility by controlling for the range of inaction caused by sunk costs. The empirical specification has a two sided Tobit structure. The results of this model are compared to results of a simpler linear benchmark model disregarding the impacts of irreversibility. Both models are applied to a Monte Carlo panel and the estimations are repeated several times. The simulation results are summarised as follows:

- Imperfect capital markets and sunk costs induce a range of inaction and thus a kinked investment function depending on the cash flow. Under these conditions the linear benchmark model provides only correct significance levels of the parameter estimates and shows a lower goodness of fit than the Tobit model.
- Under conditions of perfect capital markets accompanied by irreversibility the estimates of the linear benchmark model show a significant cash flow parameter even though an impact of the cash flow on investments is not modelled. As expected, the Tobit specification provides correct estimates.

These outcomes indicate how the results of linear models may lead to a mis-interpretation of the impact of financial variables on the optimal (dis)investment volume. Generally speaking, Tobit models are able to account for both, the three investment regimes caused by irreversibility and the capital market imperfections. Consequently, this class of models should be preferred in proving empirically the determinants of the firms' investment volume. Furthermore, empirical studies accounting for capital market imperfections should be critically examined since these do not include the range of inaction caused by sunk costs in the respective models.

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