Investment, R & D, and the Financing Decisions of the Firm

Investment, R & D, and the Financing Decisions of the Firm

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After a spell of unemployment of one week, I started in February 1991 as a Ph. D. student at the Department of Quantitative Economics of the Rijksuniversiteit Limburg. After being thoroughly trained in econometrics in Rotterdam, I looked forward to a period in which I could deepen my understanding of economics, more in particular *real* economics. I was interested in how decisions are made by agents, how they are affected by expectations and restrictions, how they result from strategic interaction among agents, what role is played by uncertainty and so on. The research proposal of my supervisors, Franz Palm and Sybrand Schim van der Loeff, offered me an opportunity to go into such questions for the modelling of R&D and investment at the level where most economic decisions are taken, viz., the micro level.

During my years as Ph. D. student I obtained 'hands on' experience with respect to the stochastic nature of research projects, with the small victories and the set backs. However not only did new questions that arose from my research push me forward, but many people that I came to know during my Ph. D. student years have stimulated me in my efforts to write this thesis. Sybrand SvdL put me on track of the recent literature and advised me during my early endeavours at modelling investment. Almost since the beginning Professor Bronwyn Hall showed interest in my project. She generously provided me with an enormous data set, that she had assembled and which was used for the empirical parts of my thesis. I was very pleased to work with her on a joint paper, a version of which is included in this thesis as chapter 5. Part of her knowledge and enthousiasm in conducting research spilled over to me.

Possibly the best opportunity to develop my research skills came in the fall of 1993 when Sybrand SvdL visited Harvard University. After I had received a Fulbright scholarship, Professor Zvi Griliches was willing to act as my host and arranged my stay at the National Bureau of Economic Research/Harvard University. He contributed to the success of my visit in many ways: he commented on my research and ideas and introduced me to other researchers in the field of R&D and productivity. I'm also grateful that he invited me to and let me participate in the productivity seminars and later the workshops at the Summer Institutes. I'm sure that the steepest part of my learning curve coincided with my stay at NBER. The staff and some of the

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Contents

Acknowledgements v

1 Introduction 1

1.1 The neoclassical theory of investment 1

1.1.1 Introduction 1

1.1.2 Investment models from the Jorgensonian era 3

1.1.3 Investment models based on intertemporal optimization 3

1.2 Financial decisions of the firm 8

1.2.1 Capital structure theories 8

1.3 The empirical literature on the relation between investment decisions and the firm's financial policy 13

1.3.1 R&D and liquidity constraints 19

1.4 The motivation and outline of this thesis 19

1.4.1 Motivation of the thesis 19

1.4.2 Outline of the thesis 21

2 Time-to-build and time-to-innovate in a model of interrelated factor demand with adjustment costs 25

2.1 Introduction 25

2.2 The factor demand model 27

2.3 Data and estimation strategy 34

2.4 Empirical results 39

2.5 Conclusions 45

Appendices

2.A The orders of the MA component of the error terms 47

2.B Data sources and construction of variables 49

2.C Lists of instruments 52

2.D Restrictions exploited by ALS estimator 53

3 The solution of the linear rational expectations model with gestation lags 55

3.1 Introduction 55

3.2 The model 56

3.3 The existence, uniqueness, and closed form representation of the solution 58
3.4 Conclusions 75

Appendices

3.A Proof of equation (3.3.4) 76
3.B Proof of equation (3.3.7) 77
3.C Proof of lemma 4 78
3.D Calculation of det(W) in a special case 80
3.E Proof of a result used in the proof of theorem 1. 80

4 Consequences of capital market imperfections for the adjustment of the stocks of physical and knowledge capital 81
4.1 Introduction 81
4.2 Agency costs: recent developments and consequences 83
4.3 Methodology 88
4.4 Empirical results 94
4.4.1 Estimation results for the partial adjustment model 100
4.4.2 Results obtained for the Euler equations 104
4.5 Conclusions 108

Appendices

4.A Derivation of the formula of the constant c in (4.3.5) 112
4.B Estimating equations and instruments 113

5 The role of working capital in the investment process 117
5.1 Introduction 117
5.2 The role of working capital in the investment process 118
5.3 The econometric framework 122
5.3.1 The Euler equations 123
5.3.2 A Q model of investment with endogenous financial regimes 132
5.4 Sample selection and properties of the data 135

5.5 Empirical results 139
5.5.1 Results obtained for the Q models 139
5.5.2 Results obtained for the Euler equations 146
5.6 Conclusions 152

Appendix

5.A Sets of instruments 156

6 Summary and conclusions 157
6.1 The main theoretical and empirical results 157
6.2 A Comparison of our results with the findings of others 162
6.3 Remaining, unresolved issues 163

Bibliography 167

List of symbols 179

Summary in Dutch (Nederlandse samenvatting) **183**

Curriculum Vitae 189

Chapter 1

Introduction

This introductory chapter consists of two parts. In the first part, a survey of various parts of the literature is given to make the reader familiar with the terminology and methodology used and the type of questions asked in this thesis, and to indicate the current state of knowledge in the research field(s) of this thesis. In particular, it reviews the recent contributions to the theoretical and empirical literatures on investment decisions and the connection between investment and financial decisions. After this survey, the second part of this chapter outlines the contents of this thesis and provides some motivation for the research described in this thesis.

1.1 The Neoclassical Theory of Investment

1.1.1 Introduction

Investments are an important link between the present and the future. As real counterpart of savings in the economy, they enable households and the government to smooth their consumption patterns over time. At the same time investments are needed to replace old capital, because it is broken-down or has become obsolete. Furthermore firms invest to enlarge the production capacity or to produce better or totally different products.

A considerable part of all capital goods is owned by firms that try to maximize their profits or the wealth of the shareholders. In pursuit of this objective, their demand for capital is generally determined by their expectations concerning sales and prices of outputs and inputs [1].

Hereafter we use the term investment for fixed business investment. Thus other categories like inventories or residential investment are left aside in the discussion. These categories are subjects that are usually studied

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[1] If the so-called substitution matrix is diagonal only the real cost of capital is of importance.

separately.

As mentioned above, investments are affected by several factors. For instance, the technology of the firm as well as the features of and developments in the markets in which the firm operates influence the investments. The intertemporal character of investment decisions can be attributed to the sort of goods that are purchased. For example, it does not only take years to build a chemical plant, but such an investment project involves the production capacity for several years due to indivisibilities. Furthermore, quick adjustments of the capital stock can be costly when increased demand for capital raises its price as would be the case in a monopsonistic market. The sources and the structure of adjustment costs will be discussed at another place in this chapter. Just like it often is impossible to enlarge the production capacity of the firm immediately, once the decision to expand is made, it cannot easily, i.e. costlessly, be reversed. In many cases capital expenditures should be considered as sunk costs, for instance in the case where the value of the plant moves up and down with the prices of the product as in the microprocessor industry. All these factors, sometimes in combination with uncertainty and the fact that investors are risk-averse, influence the investment decision.

When an investment project is big, the firm's internal funds may not be adequate to finance it. Then the firm can consider to acquire funds externally. For a number of reasons, that will be expounded elsewhere in this chapter, the gap between the cost of internal funds and the cost of external finance can become so large that projects are canceled, that would have been carried out if there would have been enough internal funds to finance them.

In the sequel of this section we will outline the neoclassical theory of investment. In particular, we will discuss models where the dynamical properties are treated explicitly rather than being superimposed, namely the so-called Euler equation model and Q model of investment. In this class of models the dynamical properties are part of the optimization problem and the parameters are identified by an assumption with respect to the way in which expectations are formed.

The motivation for reviewing only this part of the literature is twofold: it represents the more recent developments in the academic research on investment and the analysis in each chapter of this thesis is based on such models.

1.1.2 Investment Models from the Jorgensonian Era

For the sake of completeness we will devote a few sentences to models with implicit dynamics. Starting point of such a model is a (static) model for the optimal capital stock, that is assumed to depend on relative prices — the so-called Jorgensonian user cost of capital — , quantities, e.g. sales, and shocks. (Net) investment is determined by a distributed lag of the optimal stock of capital. The theory does not tell us much about the shape of the distributed lag function. This practice was only justified by pointing to the existence of delivery or gestation lags. Furthermore expectations were either static or were formed by extrapolation. Only under static expectations, the consistency of the theoretical model was tenable, while this assumption is clearly at odds with the forward looking character of investment decisions. In the original version of the neoclassical model output was even assumed to be exogenous to the firm. This cannot be reconciled with the fact that a profit maximizing entrepeneur chooses output and inputs simultaneously. As the distributed lag functions consisted of a combination of technological and expectational parameters, the Lucas critique applied to the so-called implicit models, namely that the expectation parameters that are sensitive to changes in policy, e.g. the investment tax credit, cannot be identified separately. This critique was one of the main reasons for the development of models with explicit dynamics.

1.1.3 Investment Models based on Intertemporal Optimization

The protagonists of this school, Hansen and Sargent (1980a,1980b), incorporated the dynamic aspects of the investment decision in the objective function of the firm but used, for the sake of tractability, ad hoc (linear-quadratic) specifications for the technology including adjustment costs. In such a framework, it was possible to determine a closed form solution of the Euler equations (first-order conditions), that can be shown to satisfy the so-called transversality condition. Epstein and Yatchew (1985) show that both the technology and the way expectations are formed can be identified from a system that includes the factor demand (Euler) equations as well as the production function. It is needless to say that, when only the Euler equations are estimated, one does not have to restrict the

specifications to those within the linear-quadratic class.

For expositional reasons, it is useful to derive a benchmark investment model from an intertemporal optimization problem. We present the derivation of a rather general model, that describes the behavior of a firm that has three potential sources of funds to finance its activities : retained earnings, debt and equity. Due to imperfections in the capital market, the costs of these sources of funds are not equal; there is a so-called financial hierarchy where retained earnings are a cheaper source of funds than the issue of shares. The costs of debt financing depend on its scale. Later on, we will discuss the reasons for/causes of the cost differences between the sources of funds. For the moment, we just assume the existence of the financial hierarchy.

The firm is assumed to maximize the present value of a stream of dividends, that is the value of the firm, subject to technological and financial restrictions. To keep matters easy, we assume that both output and input markets are characterized by perfect competition, that is prices are beyond the control of the firm. The firm is endowed with a production technology $Y_t = F(N_t, K_{t-1})$ where Y_t is output, N_t is labor and K_t is (physical) capital at the end of period t. Note that capital purchased today becomes productive next period. Let I_t denote gross investment of the firm. In addition to the delivery (or gestation) lag, the firm also faces adjustments cost of capital $AC(I_t, K_{t-1})$. This function is positive (outside of the origin) and convex in I_t. Thus the larger the adjustments of the stock of capital, the higher the marginal costs. The dividends obey the following equality

$$D_t = (1-\tau)\left\{ \tilde{p}_t[F_t - AC_t] - \tilde{p}_t^N N_t - r_{t-1} B_{t-1} \right\} + \Delta B_t - \tilde{p}_t^I I_t + V_t^N(1-\Xi_t) \quad (1.1)$$

where τ is the corporate tax rate, r_t is the nominal rate of interest paid on corporate bonds, $\tilde{p}_t$ is the product price, $\tilde{p}_t^N$ is wage, $\tilde{p}_t^I$ is the price of capital goods, B_t is debt, Ξ_t is a lemon's premium and V_t^N are new share issues. Capital is accumulated according to the well-known transition equation

$$K_t = I_t + (1-\delta^K)\, K_{t-1} \quad (1.2)$$

Dividends are not allowed to be negative and share repurchases are forbidden

$$D_t \geq 0 \qquad V_t^N \geq 0 \quad (1.3)$$

We abstract from taxes other than the corporate tax for notational convenience. The firm discounts the dividends using the (after-tax) required rate of return ρ. Summarizing, the firm faces the following optimization problem, where expectations depend on information until period t

$$V_t(K_{t-1},B_{t-1}) = \underset{\{B_t, V_t^N, N_t, D_t, I_t, B_{t+1}, B_{t+2}, \ldots,\}}{\text{MAX}} E_t \left\{ \sum_{s=t}^{\infty} (1+\rho)^{-(s-t)} \left\{ (D_s - V_s^N) \right.\right.$$

$$+ d_s D_s - b_s[B_s - \bar{B}_s] + v_s V_s^N - \lambda_s[K_s - I_s - (1-\delta^K)K_{s-1}] \tag{1.4}$$

$$\left.\left. + \mu_s[(1-\tau)\{\tilde{p}_s[F_s - AC_s] - \tilde{p}_s^N N_s - r_{s-1}B_{s-1}\} + \Delta B_s - \tilde{p}_s^I I_s + V_s^N(1-\Xi_s) - D_s] \right\} \right\}$$

In the literature there are several approaches to modeling the fact that high leverage is costly. First, following Hall (1991) or Bond and Meghir (1994), one could add a term to the profit function that depends on leverage and other factors that entail (agency) costs like firm size. Alternatively, an upperbound $\bar{B}_t$ could be imposed on debt, as Whited (1992) did. Such a bound can be interpreted as the debt capacity of the firm, that depends for instance on the composition of the mix of assets of the firm, e.g. the share of R&D. We have added such a constraint to the model. Then the shadow price corresponding to such a constraint can be modeled as a function of explanatory variables in the spirit of MaCurdy (1981). d_s, b_s, v_s and λ_s and μ_s are Kuhn-Tucker and Lagrange multipliers corresponding to the in- and equality constrains respectively. The solution to the firm's problem obeys the following conditions

First Order Conditions

$$N_t : \quad \tilde{p}_t \left[\frac{\partial F_t}{\partial N_t} \right] - \tilde{p}_t^N = 0 \tag{1.5a}$$

$$I_t : \quad \lambda_t = \frac{\partial V_{t+1}}{\partial K_t} = \left\{ \mu_t (1-\tau)\tilde{p}_t \left[\frac{\partial AC_t}{\partial I_t} \right] + \mu_t \tilde{p}_t^I \right\} \tag{1.5b}$$

$$K_{t-1}: \quad \lambda_{t-1} = E_{t-1} \left\{ \frac{(1-\tau)}{(1+\rho)} \mu_t \tilde{p}_t \left[\frac{\partial F_t}{\partial K_{t-1}} - \frac{\partial AC_t}{\partial K_{t-1}} \right] + \frac{(1-\delta^K)}{(1+\rho)} \lambda_t \right\} \tag{1.5c}$$

$$D_t : \quad 1 + d_t = \mu_t \qquad d_t D_t = 0 \tag{1.5d}$$

$$B_t : \quad b_t - \mu_t + \mu_{t+1}[(1-\tau)r_{t-1} + 1](1+\rho) = 0 \qquad b_t[B_t - \bar{B}_t] = 0 \tag{1.5e}$$

$$V_t^N : \quad -1 + v_t + \mu_t(1-\Xi_t) = 0 \qquad v_t V_t^N = 0 \tag{1.5f}$$

Transversality Condition

$$\lim_{s \to \infty} E_t \left[(1+\rho)^{-s}\tilde{p}_{t+s}[F_{K,t+s} - AC_{K,t+s}] - \tilde{p}^I_{t+s-1}\right] K_{t+s-1} = 0 \tag{1.6}$$

No Ponzi Game Condition

$$\lim_{s \to \infty} E_t \left[(1+\rho)^{-s} B_{t+s}\right] = 0 \tag{1.7}$$

Equation (1.5b) equates the marginal costs of investment to the present value of the marginal reveneus of investment net of adjustment costs, λ_t . This relation between the marginal adjustment costs and λ_t , which is also referred to as (Tobin's) marginal Q, was first demonstrated by Mussa (1977) in a deterministic context. Hayashi (1982) has shown for a deterministic model in continuous time that under perfect competition this non-observable shadowprice of capital equals the ratio of the market value of the firm over the replacement value of its capital stock — the average Q — if and only if the technology is homogenous of degree one [2]. Note that Hayashi (1982) did not take financing considerations into account in his analysis. This relationship between marginal Q and average Q can also be demonstrated in a stochastic context [3]. See also Abel (1983), Hayashi and Inoue (1991) and Galeotti and Schiantarelli (1991). The latter authors generalize the Q model of investment by allowing for monopolistic competition and non constant returns to scale as

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[2] The value of the firm should be adjusted for a term that equals the present value of future tax deductions attributable to past investments.

[3] To this end, multiply equations 1.5a-1.5c with the corresponding variables, add them up and make use of the fact that the technology is linear homogenous to obtain $\lambda_{t-1}K_{t-1} = V_t - Z_t$ where $Z_t = \sum_{s=t}^{\infty}(1+r)^{-(s-t)}[\Delta B_s - (1-\tau)i_{s-1}B_{s-1}]$.

well as more than one quasi-fixed input.

Some authors have been worried about the assumption of homogeneous capital, which is maintained in the naive applications of the Q theory, where all kinds of capital are simply added up. Chirinko (1993b) relates an average Q measure to a combination of investment ratios, where the coefficients are ratios of adjustment coefficients. Hayashi and Inoue (1991) introduce a capital aggregator defined on a vector of various types of capital. This aggregator allows them to break the firm's optimization problem into two stages. First they determine the optimal path of the scalar capital aggregate over time. Next they solve the static problem of partitioning the aggregate into individual capital stocks in order to minimize the cost.

An important difference between the Q theoretical approach and the Euler equation approach, is that the former is based on efficiency of the stock market while the success of the latter crucially depends on the specification of the production function. As both approaches start from the same optimization problem, they can be viewed as complementary.

In the previous part we already mentioned that one source of dynamics in capital demand is the fact that adjustments of the capital stock are costly. This notion dates back to the work on investment by Eisner and Strotz (1963). In the early literature on investment that relied on the existence of adjustment costs a simple convex quadratic function lie $\alpha(\Delta K_t)^2$ was usually adopted. Another quadratic specification for adjustment costs which is often used in the derivation of the Q model is $\alpha(I_t/K_t - \beta)^2 K_t$. Note that the latter function has the attractive property of being linear homogeneous, which rules out size effects on capital demand. While these specifications are very convenient from a mathematical point of view, their economic theoretical appeal is open to much skepticism. Rothschild (1971) argues that indivisibilities and transfer of information are aspects of actions that are part of the adjustment proces. Both give rise to essentially fixed adjustment cost. For instance it requires at least one teacher to train one worker how to operate a new machine. Presumably this teacher can also train five workers at the same time. Abel and Eberly (1994) incorporate fixed adjustment cost inter alia in a Q model of investment. Recently Caballero and Engel (1994) presented a model for investment that is obtained by aggregating over many firms with possibly different fixed adjustment cost schedules.

1.2 Financial Decisions of the Firm

Part of this thesis deals with the interrelationship between financial and investment decisions by firms. The aim of this section is to give a more general background on this subject for the readers of the respective chapters. Specific parts of the literature that are directly relevant for the research, motivation and reasoning, are discussed in the chapters themselves. As our thesis tries to fill gaps in the empirical literature as where it stands today, we will also give an overview of the recent developments. In doing so we will follow Main Street and indicate the potholes . As will become clear, part of Main Street could have been named "Q" Avenue, but at the end of the street we will turn to some research based on Euler equations. Before we walk down the road, we will first discuss the theoretical literature of the capital structure. The focus of that sub-section will be on those parts of the literature that have some bearing on investment decisions.

1.2.1 Capital Structure Theories

Assuming a perfect capital market and a given investment policy, Modigliani and Miller (1958), MM for short, proved their famous

Proposition I

The market value of the firm is independent of its capital structure, and is given by capitalizing its expected return at the rate appropriate to its risk class.
or phrased differently: if there are two firms in the same risk class, the debt-equity ratio of any particular firm is indeterminate.

The MM proposition I follows from the value-additivity principle, which is based on a subset of the assumptions underlying their original proof. For instance, in contrast to the proof given by MM which is based on an arbitrage argument, it does not require the existence of two firms with identical streams of cash flows (up to a scale factor).

MM (1963) give a generalization of proposition I for the case with taxes. Then the value of the firm equals the value of an all-equity firm plus the present value of tax shields that arise from interest deductions on all

present and future debt. Thus the manager of the firm has an incentive to maximize the use of debt.

An important corollary to the first MM proposition is that investment and financing decisions are not interrelated.

The MM theorem holds under a long list of assumptions that define the notion of a perfect capital market. Most of them are more or less unrealistic. However the importance of the MM article lies in the fact that it identifies the sources of market imperfections which will affect the choice of the capital structure and thereby the value of the firm.

Before we discuss the assumptions we make three remarks. While the leverage of the firm is indeterminate (or infinite) according to the first MM proposition, this is not necessarily true for the debt-equity ratio of the whole economy. Miller (1977) proposed a model for an economy with taxes, where the ratio is determined by the corporate tax rate and the wealth of investors in various tax brackets. Second, as was recognized by DeAngelo and Masulis (1980), firms with high losses cannot deduct their interest expenses to the full extent and may therefore have less debt. Third in Miller and Modigliani (1961) it is shown that, in a perfect capital market with no taxes, dividend policy, defined as the trade-off between retaining earnings and paying out dividends (issuing shares), does not matter given the investment and borrowing policies of the firm. Taken together MM have given conditions for separability of financial and real (investment) decisions. We now turn to their (perfect market) assumptions :

I Complete and Efficient Markets

1) All types of securities are available in the market, so the firm cannot create a new type of security.
2) Salability of tax losses.
3) Corporate insiders and outsiders have the same information and the information is acquirable at zero cost (symmetric information, i.e. no signaling opportunities)
4) Capital markets are frictionless.
5) Efficient markets (no arbitrage opportunities).
6) Equal access: investors and firms can borrow, lend and issue claims on the same terms.

II Holding the cash flow constant (no growth options)

1) Neutral personal taxes.
2) Managers always maximize shareholders' wealth (i.e. no agency costs).
3) No bankruptcy costs (another source of agency costs).

Note that the MM result is conditional on the stream of cash flows of the firm. This, of course, is not a property of perfect capital markets.
By studying the consequences of relaxing one or more of the assumptions listed above one obtains a better understanding of capital structure. Harris and Raviv (1991) provide an excellent survey of the theory of the capital structure. Apart from taxes they classify the determinants of the capital structure into four categories. The determinants are the desire to [4]

- ameliorate conflicts among various groups with interests in the firm, including managers. (principal-agent approach)
- convey private information and mitigate adverse selection effects. (asymmetric information approach)
- influence the nature of products or competition in the product/input market
- affect the outcome of corporate control contests.

We will briefly summarize the seminal papers in the first two categories. The third category, which in principle is interesting since we are also studying investment in R&D, is in statu nascendi and has not much to tell us sofar. Most corporate finance theories that have implications for investment in R&D and take its special characteristics into account, belong to the first two categories.

With regard to the first group, Jensen and Meckling (1976) distinguish two types of conflicts of interest: first conflicts between equityholders and managers and second conflicts between bondholders and shareholders. When managers hold only a small fraction of the shares, the price managers pay for consuming perquisites like luxurious offices and reducing effort is low. If the firm is levered up, a larger portion of the equity will represent the investment of the manager in the firm. As a result, managers will refrain from

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[4] Quoted from Harris and Raviv.

squandering cash flow. Moreover, Grossman and Hart (1982) argue that if bankruptcy is costly for managers, they will work harder in a highly leveraged firm. The optimal leverage corresponds to a balance between the benefits of debt and the costs of debt, such as monitoring and bankruptcy costs. High leverage may also create an incentive for the owner/manager to "go for broke," that is to engage in activities with a very high payoff with a low probability. If such a project turns out to be a failure, the debtholders bear the costs. However this behavior is likely to be anticipated by the creditors and eventually the shareholders bear the cost by receiving less when issuing debt. Myers (1977) points out another disadvantage of debt which is the mirrorimage of the conflict just mentioned. When firms are close to bankruptcy, equityholders may have no incentive at all to invest in a positive net present value project, because the proceeds are captured mainly by creditors.

In Jensen (1986) and Stulz (1990), managers are assumed to overinvest, that is they invest all available funds even if the projects are not positive NPV. Then debt may serve to reduce so-called free cash flows in the interest of the shareholders. According to Stulz, interest payments may become a burden by absorbing/exhausting funds needed for profitable investment projects. In an extreme case the inflexible debt contract can lead to liquidation. The cost of debt is higher to the extent that assets are more firm-specific. For this reason, Williamson (1988) argues that for example R&D intensive firms should have a lower debt-equity ratio.

The second important branch in the capital structure theory builds on the notion that insiders, like the manager, have information that outsiders do not have and that the transfer of this information is costly. This could for instance be information about investment opportunities. It is tempting for managers to exaggerate the quality of a project when verification of the true characteristics is costly, when this would reduce the cost of external funds. However the cost of these funds depends on the expectation of the quality of the project given the (limited) information of the outsider, that is on the average quality of projects. Therefore when the information asymmetry is not (partly) abolished, some good projects will not be undertaken as the funds will be too expensive. The manager can solve this problem by providing a credible signal about the quality of the firm. In Leland and Pyle (1977) the manager is assumed to be risk-averse. As he owns part of the firm, the manager benefits from increases in the value of the shares. By levering up, the stake

of the manager in the firm increases (cf. Jensen and Meckling). On the other hand the welfare of the manager increases less/decreases more to the extent that the quality of the firm is lower. Thus managers of high quality firms can signal this by allowing more debt in the capital structure, which will result in an increase of the value of the shares. In Ross' (1977) model the manager's reputation is harmed, if the firm goes bankrupt. Managers of high quality firms can signal this by issuing more debt. Investors will associate high leverage with high quality, since lower quality firms will not choose such a capital structure because they have higher expected bankruptcy costs.

According to Myers and Majluf (1984) the extent to which firms underinvest depends on their marginal source of funds. For example when a project with positive NPV can be financed by issuing riskless debt, which is not subject to undervaluation, it will be undertaken as the shareholders receive all the profits of this project. On the other hand, the decision to invest could be negative if the firm could only issue (risky) equity, which is likely to be undervalued under asymmetric information. It follows that firms have a preference order for sources of finance. Thus according to this line of reasoning, which Myers (1984) dubbed the "pecking order" theory of financing, new investments will preferably be financed internally, then with low-risk debt and as a last resort with equity. Note that this is a dynamic theory that tries to explain changes in the capital structure rather than a static theory that gives the optimal levels of debt and equity. Secondly, while Jensen and Stulz stress the possibility of overinvestment, Myers and Majluf point to the possibility of underinvestment. Third in addition to asymmetic information problems, bankruptcy risk and transaction costs, there are other factors that explain why internal finance is cheaper than external finance. Auerbach (1979) shows that taxes create a wedge between the marginal costs of internal finance and new shares. Finally we note that asymmetric information problems not only raise the cost of external finance but can result in credit rationing, see Stiglitz and Weiss (1981). For a discussion of the literature on the effect of agency cost on the availability of external funds we refer to chapter 4.

Numerous articles have appeared, since the papers that were outlined above appeared. Only a few articles lead to opposite conclusions. For instance, Jensen predicts a positive correlation between leverage and free cash flow. On the other hand Myers and Majluf expect a negative correlation.

There is an empirical literature that has tested many predictions of

these theoretical papers. With respect to the conflicting result mentioned above, the evidence supports the Myers and Majluf paper. But Korajczyk et al. (1990) find that leverage decreases in the two year period before an equity issue. This finding casts some doubt on the pecking order theory.

Important questions remain. Do we really need a capital structure to signal or to discipline managers? Why do we not use a standard incentive scheme? Hart (1991) argues why the capital structure may be a better tool to control managerial behavior, than a compensation scheme.

Finally a literature has emerged in recent years that tries to answer the more fundamental question why securities have the characteristics that they have. Harris and Raviv (1990) review this literature. Important early papers are Townsend (1979) and Gale and Hellwig (1985).

1.3 The Empirical Literature on the Relation between Investment Decisions and the Firm's Financial Policy

There are several theories that arrive at a link between investment and the availability of cheap funds. Many empirical papers — mostly American — have investigated whether the inclusion of financial variables would improve the fit of investment models.

At the end of the fifties, when Modigliani and Miller proved their famous proposition that financial and investment decisions are not interrelated, Meyer and Kuh (1957) investigated the empirical relation between internal liquidity and investment. They found that liquidity, which was measured by profits and depreciation expenses, is of importance for explaining the investment behavior of all firms, particularly of small firms. Furthermore, the sensitivity of investment to liquidity was found to vary with the stage of the business cycle and the growth-trend of the industry: in a recession liquidity influences investment to a large extent. However in the long run capacity considerations dominate the demand for capital.

As early as in 1939 Tinbergen used profits as an explanatory variable for investment. His results showed that this variable performs well. However according to Grunfeld (1960) profit is a surrogate variable, which tends to be strongly correlated with the main forces that cause changes in investment. He argues that the market value of the firm in conjunction with an estimate of the replacement value of the physical assets of the firm reflect better the

expectations upon which investment decisions are based. Unlike earlier studies, his article presents empirical evidence that shows that the interest rate affects investment.

A vast majority of the studies on investment that appeared in the sixties and seventies was based on the assumption of a representative firm but reached different conclusions with regard to the importance of internal finance for explaining investment behavior. One of the exceptions was Eisner (1978), who corroborated the result of Meyer and Kuh that investment of smaller firms is more sensitive to profits than larger firms.

Poterba and Summers (1983) formally derive and test a Q model of investment, that pays attention to cost differences between internal and equity finance due to differences in tax treatment. A drawback of their analysis is their assumption that the debt-capital ratio is given to the firm. Hayashi (1985) presents a model in which financial and investment decisions are simultaneously determined. Assuming that the equity value of the firm depends on debt only through the debt-capital ratio and working within the standard linear homogeneous framework, he arrives at a financial hierarchy with three regimes. In the first regime, which is characterized by dividend payments, marginal investment is partially financed by retentions, while in the third regime new shares are the marginal source of funds. In all regimes debt finance is a constant fraction of incremental investment. In the second regime, where debt is the marginal source of financing, a relation between investment and some Q fails to exists, while in the other regimes the relations derived in Poterba and Summers still hold. In Chirinko (1987) the debt level is determined by the firm and enters the optimization problem of the firm through a term that captures agency and transaction costs. He shows that average Q signals investment opportunies both in physical and financial assets and therefore debt should be included in a Q model of investment.

Bond and Meghir (1994) stress that the financial regime that is relevant to the firm, is endogenous as it depends on the volume of profits, and changes over time.

In their important paper Fazzari, Hubbard and Petersen (1988), FHP for short, split their sample of firms according to their dividend-income (pay-out) ratio, and estimated two important investment models — the Q model and the sales accelerator — after adding cash-flow to capture the liquidity of the firm, on the basis of the subsamples. The idea behind this strategy was

that firms with a high pay-out ratio are less likely to be liquidity constrained and, as a consequence, their investment should be less sensitive to cash flow. Their findings supported this idea. However their approach gave rise to critique concerning a number of issues. First if the marginal Q is not correctly measured by average Q, cash flow may act as a proxy for expectations concerning profitability. This could explain why even investment of firms with a high dividend pay-out ratio reacts to fluctuations in cash flow. Second, according to the liquidity theory, investment depends on the *stock* of internal funds (retained earnings) rather than the cash *flow*. Third the variable on which the classification was based was measured by using within-sample information. Again when the pay-out ratio is correlated with profit expectations, this changes the interpretation of the results.

In the spirit of FHP, Oliner and Rudebusch (1992) investigated how the parameters of Q and cash flow vary across firms with variables that measure the severity of asymmetric information problems, the height of agency costs and the height of transaction costs. They conclude that the first category of market imperfections is the prime source of the existence of a financial hierarchy.

Abel and Blanchard (1986) investigated whether the poor performance of the Q model of investment (when using aggregate data) was due to mismeasurement of marginal Q, which is usually replaced by average Q. To this end they constructed a series for marginal Q using a VAR approach. Their regression results resembled the results that are based on average Q, in that marginal Q significantly explains investment but also yields large, serially correlated residuals. Furthermore output and profit significantly improved the fit of the model when added.

Blanchard, Rhee and Summers (1990) posed the question whether managers should let their investment decisions depend on the stock market valuation of the firm, even if it does not reflect its fundamental value. They list a number of reasons why managers should follow either the stock market's or their own (fundamental) assessment of the value of the firm, which is likely to be based on better information. What firms actually do is an empirical question, which they have tried to answer by investigating the sensitivity of investment to both valuations following two approaches. First they factorized Q as a 'fundamental Q' times the ratio of the stock market value over the fundamental value, and used a number of alternative proxies for fundamentals.

Second they examined the performance of the Q model in periods around stock market crashes when fundamentals and stock market valuation were likely to differ a lot. They argued that if fundamentals determine investment, then the relation between market value and investment should be weaker during this period. They find some evidence that fundamentals rather than the quoted price of the firm, matter for investment.

Gilchrist and Himmelberg (1991) also attribute the failure of the traditional Q model to deviations of the stock market value from the fundamentals which are thought to be the true forces explaining investment. They apply the methodology of Abel and Blanchard to firm level panel data in order to test the Q model of investment. By employing a recently developed method for estimating VARs with panel data, they were able to construct marginal fundamental Q's of firms, which accommodate for unobserved heterogeneity. Furthermore, in contrast to the work of most predecessors, their parameters had a structural interpretation. Unlike Abel and Blanchard, Gilchrist and Himmelberg find support for the Q model when Q is measured by their fundamental Q. Furthermore Tobin's Q and the fundamental Q are only weakly correlated which seems to be due to failure of market rationality. Not surprisingly perhaps, Tobin's Q performs worse than fundamental Q as explanatory variable for investment and yields an unreasonable high adjustment cost parameter.

Using the same type of framework Gilchrist and Himmelberg (1993) turn to the question whether investment is (excessively) sensitive to cashflow because it is the cheapest source of funds in a financial hierarchy or because of its ability to predict future profitability of the firm. They point out that finding different values for the coefficients of cash flow in a Q model for different categories of funds can well be reconciled with the latter explanation of the role of cash flow : for example, changes in cash flow will lead to a very different revision of profit expectations at small, high growth firms than at older firms. As a consequence, they consider the evidence of Fazzari, Hubbard and Petersen as inconclusive at this score. Notwithstanding this critique on FHP, their structural interpretation of the evidence for the (reduced form) coefficients of cashflow and the assumption of a delivery lag of 1 year, allow Gilchrist and Himmelberg to reach the same conclusion as FHP did, namely that investment is excessively sensitive to cash flow because it is a cheap source of finance rather than 'only' a fundamental.

Chirinko and Schaller (1993) investigate whether the stock market is efficient, and, if not, whether the financial and investment policies of the firm are affected by bubbles — the supposed sources of the inefficiency — by estimating the Euler and the Q equation in a simultaneous equations model and testing different hypotheses which take the form of orthogonality conditions. They exploit the fact that the Euler equation and the Q model hold under different conditions and as a consequence they can yield different pieces of information. The acceptance of the Euler model and the rejection of the Q model (by the MESH test due to Eichenbaum *et al.* (1988)) indicates that the stock markets are inefficient, but also that firms rely on their own expectations when taking investment decisions and do not take advantage of overvaluation of their shares.

The fact that firms endogenously switch financial regimes was fully recognized by Corres, Hajivassiliou and Ioannides (1993). They modeled the qualitative aspects of investment and financing and dividend decisions by means of a dynamic limited dependent variables model, which was subsequently estimated on the basis of firm data controlling for individual heterogeneity with a general stochastic structure for unobservables. The discreteness of the investment decision was justified by the plausible concavity of adjustment costs, which leads to 'all or nothing behavior'. In this paper the financing decisions are modeled both as univariate and as multivariate discrete events. The latter framework allows for interdependence among the financing decisions. The models, that included firm fundamentals and lagged values as explanatory variables, performed well and reveal high persistence in the firms' qualitative decisions. Furthermore heterogeneity was found to be important.

Gross (1994) also takes a 'high tech' approach to the modeling and estimation of the investment and financing behavior of firms that are possibly liquidity constrained. Starting from a structural theoretical model that is reminiscent of the buffer stock consumption literature, he derives optimal investment, retained earnings, borrowing and dividend policies as function of the internal financial assets. These functions are nonparametrically estimated to capture the nonlinearities that are predicted by the theory. For instance, as is known from the agency costs literature, when the firms have few internal resources and face the possibility of bankruptcy , they can become either extremely risk-averse to stay in business or risk-loving because they go for broke. The evidence indicates that the firm's capital depends on the financial

resources in the nonlinear way that was predicted by the theory. Furthermore the investment of firms that borrow is less sensitive to internal funds and highly leveraged firms behave as risk-lovers.

Hall (1992) identifies the liquidity effect of cashflow by instrumenting with lags two and three of the endogenous variables (measured once a year). Since demand shocks are not forecastable, no relationship should be found between cashflow and investment under this interpretation of cash flow fluctuations unless firms react very slowly to demand shocks. Applying this methodology she finds that there are liquidity effects on both ordinary investment and R&D expenditures. Furthermore, like Long and Malitz (1985), she finds that leverage and the level of R&D investment are strongly negatively correlated across firms and moreover that this cannot be explained by tax considerations, i.e. the fact that both R&D and interest expenses can be deducted against taxable income and can substitute for each other. However this negative correlation could be due to the intangibility of R&D.

While the approach in the former paper was non-structural, in another paper by Hall (1991) a set of Euler equations is derived from a firm value maximization problem subject to financial constraints, for a firm that invests in ordinary capital and R&D. These first order conditions depend on ratios of the shadow prices of the flow of funds constraints in subsequent years. Next the sample was split according to the (presumed) values of these ratios and the equations were estimated on the basis of the subsamples. The results she obtains are fragile and instable and at several points inconsistent with the predictions of the model. As one of the potential causes, she mentions that information that is needed to assign observations to subsamples is contaminated by noise due to measurement errors. Furthermore she identified the regime (assesses the value of the ratio of the shadow values) by looking at the observed dividend payments or share issues. However dividend policy not only depends on cash availability in the short run but could also be driven by the desire to signal information to outside investors. As negative changes could be interpreted as a bad signal about the perspectives of the firm, which would lead to higher costs of external finance, firms are very reluctant to cut dividends when their liquidity is temporarily low. Therefore some other indicator of liquidity like, for instance, working capital, which also displays more variability, may be more instrumental for splitting the sample. When the sample was split according to information on share issues, the results were somewhat better than when dividends were used.

1.3.1 R&D and Liquidity Constraints

For several reasons which are mentioned in chapter 4, R&D is thought to be especially sensitive to the availability of internal finance. The older empiricial literature that tests this hypothesis, which was already entertained by Schumpeter (1942), is summarized in Kamien and Schwartz (1982). However the studies cited in that book hardly found any evidence in favor of this thought, which however is widely believed to be true. Recent research on this topic includes Hall (1991,1992, the main findings have already been mentioned above) and Himmelberg and Petersen (1994). The latter ran regressions of R&D expenditures on cashflow paying much attention to econometric issues. They argue that due to high adjustment costs, R&D is not responsive to the transitory component of cashflows. Employing several strategies to estimate the elasticity of R&D with respect to the permanent component, they find a value of 0.67 for their sample of small high-tech firms.

1.4 The Motivation and Outline of this Thesis

1.4.1 Motivation of the Thesis

The common theme of the chapters in this thesis is the modeling of investment decisions. One chapter (chapter 3) presents a theoretical analysis of the solution of an important investment model, whereas the other chapters report on empirical research on investment in both physical capital and R&D. Although each chapter is self-contained, the empirical chapters are interrelated in that they essentially try to answer two questions using American firm data from five industries that form the so-called scientific sector within the manufacturing sector [5]:
first can we explain the behavior of the investment processes satisfactorily by carefully modeling the technological aspects that are inherent in these processes — this is the focus of chapter 2 — and second can we improve the explanatory power of investment models by paying attention to financial

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[5] The industries are at the two digit level using the Standard Industrial Classification codes.

considerations and conditions, such as the cost of external funds or the presence of liquidity constraints? The latter question motivated the research carried out in chapters 4 and 5.

In the empirical literature, most studies have found that 'output variables' are more important for explaining investment than 'price variables', see e.g. Shapiro (1986b). Mismeasurement of the latter is often mentioned as one of the culprits. An important price variable that has often been left out from the investment equations is cost of funds.

Capital market imperfections can interfere with investment decisions in various ways. In chapter 4, the financial accelerator theory is tested, which explains how agency costs *accelerate* the *adjustment processes* of the capital stocks. In chapter 5, versions of the Euler equation model and the Q model are estimated that feature liquidity constraints and an upward sloping supply curve of funds. This approach stresses the effects of capital market imperfections on the *volume* of investment spending. The treatment of the liquidity constraints in the empirical literature has not been very satisfactory, or successful for that matter, on the whole. The emphasis in this chapter is therefore on deriving new implications of the models, that might help to gauge the importance of liquidity constraints in explaining ordinary investment and R&D.

The mechanisms investigated in chapter 5 have a lasting effect on the volume of investment, whereas the financial accelerator mechanism merely affects the timing of investment. Nevertheless, the latter mechanism could be an important factor in explaining business cycles.

The consideration of R&D is motivated by a number of reasons. First R&D is not just a type of capital, but it has some important characteristics that distinguish it from other types of capital: it is both an input to the production process and a source of monopoly power. As an input it leads to process innovations, which reduce the costs of production, and to quality improvements of the products or even to new (varieties of) products. This helps the firm to gain or retain monopoly power.

Second, as stressed by Schumpeter (1942), especially R&D intensive firms depend upon internal finance for investment. He argued that innovation is therefore greater in monopolistic industries than in competitive industries, because firms in those industries can appropriate the profits generated by its own innovations to a larger extent. Moreover, Arrow (1962) recognized that

firms have an incentive not to reveal information on R&D projects, to ensure maximal appropriability of their innovations. This fact causes asymmetric information problems between entrepeneurs and investors to last. Thus unlike physical capital, R&D is actually both an explanatory variable and a variable to be explained in a study of factor demand subject to financial constraints.

In order to estimate the models and test implications of various theories in an adequate manner, the properties of the actual data will be investigated and econometric issues will be dealt with. We will now give a brief outline of the contents of the chapters in this thesis.

1.4.2 Outline of the Thesis

Chapter 2 is concerned with the estimation of dynamic factor demand relations for R&D, physical capital and employment. They are derived from an intertemporal cash-flow optimization problem that incorporates a general description of the production technology and adjustment processes. Both are approximated by second order polynomials. Furthermore allowance is made for gestation lags in the building processes of knowledge [6] and physical capital and for interrelation between the inputs and changes in the inputs all of which are assumed to be quasi-fixed.

The heterogeneity of the firm data is accounted for by modeling the technology and adjustment parameters as a function of firm size and factor intensities.

Identification of the parameters relies on the assumption that the managers/owners of the firm have rational expections with respect to the driving processes of factor demand like prices.

The model is estimated in two stages: first estimates of the parameters of the Euler equations (f.o.c.) are obtained by applying the Generalized Method of Moments. Next the restrictions between these parameters and the structural parameters that are implied by the model, are exploited by the minimum distance method to yield estimates of the latter. This procedure allows for the possibility to select those restrictions that provide the most reliable information on the structural parameters one is interested in and will result in more robust estimates in general.

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[6] In this thesis knowledge capital is used as a synonym of the stock of R&D.

To carry out the first step of the estimation procedure, moment conditions have to be specified. Attention is paid to the consequences of ordinary, well-known problems such as the presence of individual effects and measurement errors, when formulating the moment conditions. Furthermore, in order to select conditions that produce relatively precise estimates, the time series properties of the stocks of the inputs will be investigated. It will turn out that, apart from the well-known problem of heterogeneity, the near random walk behavior of the input series is responsible for the weak identification of parameters of interest. This is perhaps the most important message of this chapter, that one should be aware of when studying productivity issues or factor demand with firm level data.

We test various hypotheses concerning the character of the adjustment cost, like separability from levels, symmetry and convexity and the order of the gestation lags. The test results indicate that strong separability of the adjustment costs cannot be rejected and furthermore that joint convexity of the adjustment cost function of the three factors of production is not tenable. At the end of chapter 2 the distribution of the components of the adjustment costs of the firms in the sample is calculated.

Chapter 3 can be considered as a companion to chapter 2. In this chapter the symmetric Linear Rational Expectations Model of Kollintzas (1985) is generalized by allowing for time-to-build. The properties of the solution space are investigated. By using a decomposition of the matrix lag polynomial of the Euler-Lagrange conditions that encompasses that for the Kollintzas model, it is shown that the extended model admits a unique stable solution. The stability condition provided by Kollintzas turns out to be valid for this model too. It translates into an equivalent condition on the revision processes which together with other conditions on the revision processes provided by Gouriéroux et al. completely restict the revision processes. The latter conditions ensure the equivalence of the Euler-Lagrange conditions and the reduced form in terms of realizations and revision processes. At the end of the chapter a procedure is suggested to obtain a closed form solution or when the driving processes are too complicated a semi closed form solution. The asymmetric model is also considered.

In chapter 4 we investigate whether the adjustment behavior of firms is related to financial factors. The financial accelerator theory purports that firms that are likely to face higher agency costs of borrowing, e.g. small,

R&D-intensive or highly leveraged firms, adjust their stocks of knowledge and physical capital at a quicker pace than the average firm to save on interest payments and/or to reduce the probability of bankruptcy. The theory is tested using two models. For both R&D and physical capital a version of a simple partial adjustment model is estimated, where the speed of adjustment is modeled as a function of firm size, leverage and R&D intensity. In addition Euler equations are estimated after splitting the sample on the basis of leverage. For both types of models we have also allowed for asymmetry in (adjustment) behavior between booms and recessions since the implications of the financial accelerator theory are likely to manifest themselves more sharply during recessions. The structural model underlying the Euler equations includes a Cobb Douglas knowledge production function, that is more consistent with the persistence of changes in knowledge capital. The results can be summarized as follows:

First, we found that the speed of adjustment of physical capital is higher for smaller firms. Second, the adjustment speed of the stock of physical capital does not depend on the firm's leverage nor on its R&D intensity. Third, when we imposed symmetry of behavior across the business cycle, we found that both the level and the adjustment speed of R&D are higher for smaller firms and firms with a lower debt-assets ratio. However, these effects of firm size and leverage on R&D disappeared once we allowed for asymmetry. Finally, stability tests of the estimates across stages of the business cycle indicated that the adjustment speeds of both R&D and physical capital are higher in a period of economic contraction. However this finding is not related to factors that affect the height of agency costs. The higher adjustment speed of smaller firms is therefore interpreted as a reflection of their flexibility.

Chapter 5 centres on estimating the effects of liquidity constraints on the accumulation of capital. As we have seen in sub-section 1.1.3, the Euler equation model and the Q type model, that allow for the presence of liquidity constraints, contain unobservable shadow values of funds, that cannot be ignored at the estimation stage. Our solution to this problem was to exploit another Euler equation that corresponds to working capital and to add an assumption to the model concerning the behavior of the shadow value of working capital. This approach resulted in a relationship between the unobervable shadow values of funds and working capital. We argue that this variable is

likely to measure the (change in) the liquidity position of the firm more accurately than other variables that have been used in the past by others.

We also show that a proper test of capital market imperfections within a Q theoretic framework concerns the constancy of the coefficient of Q across financial regimes, rather than the significance of the coefficients of liquidity measures, such as cash flow or sales. The latter approach is ad hoc and raises questions about the interpretation of the effect of cash flow (sales) on investment.

To test for the constancy of the coefficient of Q across financial regimes, we estimated an endogenous switching regression model, where the sign of the change in working capital determines the regime. The main problem we encountered here was to specify a model that predicts the change in working capital well. Therefore we also estimated models assuming that we can predict the regimes perfectly.

The empirical evidence on the effects of working capital on investment is in agreement with the theory but rather weak. More significant results were obtained with respect to the supply curve of funds. In all models debt had a depressing effect on investment. We interpret this finding as follows: the higher the debt-assets ratio, the higher the (agency) cost of financing R&D expenditures and investment.

Chapter 6 summarizes the main findings of this thesis and compares them with the results of other studies. It also discusses some fundamental problems related to the measurement of the stock of R&D and to the estimation methods and testing procedures that are employed in this thesis. Although these problems are not the focus of this thesis we mention them because they affect the results that are reported or the way they should be interpreted.

Chapter 2

Time-to-build and Time-to-innovate in a Model of Interrelated Factor Demand with Adjustment Costs

2.1 Introduction

In the past decade several studies have appeared that treated R&D efforts as an input that contributes to the productivity of the firm, e.g. Griliches and Mairesse (1983, 1984), Nadiri and Bitros (1980), Mairesse and Siu (1984) and Bernstein and Nadiri (1988). The last three papers recognized the quasi-fixity of both physical capital and knowledge capital (R&D) but ignored the presence of gestation lags. In the model investigated by Hall and Hayashi (1988) on the other hand, time-to-build plays a crucial role but adjustment costs are not explicitly considered as an explanation of the dynamics displayed by the capital stock series [1]. In this chapter a model is presented that takes both features into account. The factor demand relations, which include labor demand, follow from maximization of the present value of the stream of cash flows under uncertainty. We adopt a quadratic polynomial approximation to the production technology. Furthermore we assume a quadratic adjustment cost function and allow for interrelations between the inputs [2]. It can be shown that this model admits a unique stable solution (see chapter 3).

For the empirical investigations and statistical inference we have relied on panel data pertaining to firms in industries that belong to the U.S. scientific sector. As is well-known the use of aggregate data for representative agent models can lead to spurious (or misleading) results, e.g. see Wolfson (1993) and Gordon (1992) in particular on the aggregation problem with respect to adjustment cost specifications. Epstein and Denny (1983)

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[1] Their accumulation rule for knowledge capital, which could be interpreted as a knowledge production function, has some properties that are characteristic of an adjustment cost mechanism.

[2] We will refer to this model as the basic model.

derive and empirically reject restrictions on a quadratic value function that permit aggregation across firms.

Because of the tremendous amount of heterogeneity in panels of firm data, modeling the differences between firms in a proper way is at least as important as describing the dynamics of the series. Therefore we respecify the basic model. Since much of the heterogeneity is related to the fact that the factor intensities vary over the firms, we let the adjustment costs function depend on relative changes of the inputs of the firm and on the firmsize. Expressions are derived and next substituted for the parameters of the production function assuming that it approximates a Cobb-Douglas technology. These formulae provide a link between the parameters and some sources of heterogeneity, such as the elasticities. Because we are mainly interested in the parameters of the adjustment cost function, the elasticities are replaced by linear functions of the cost shares thereby referring to the first-order conditions in the stationary situation. Locally the more flexible model that we obtain in this way resembles the basic model and therefore we believe that the stability property will carry over.

Since it is not feasible to derive a closed-form solution (CFS) for the flexible model, the Euler equations are estimated directly applying the generalized method of moments (GMM). In the second stage, the structural parameters are estimated using the method of asymptotic least squares (ALS) which minimizes the distance between the estimates of the unrestricted Euler equation parameters and functions of the (over-)identified structural parameters.

Palm *et al.* (1993) considered a model that is related to our basic model but assumed absense of interrelations. Using aggregate data they obtain estimates of the parameters that determine the building scheme. Since we lack accurate information on the tax status of firms, we were not able to calculate prices at the firm level. Therefore we will not endeavor the estimation of these time-to-build parameters. However, like Wolfson (1993), we can still identify the (maximum of the) gestation lags by testing the validity of the instruments. Furthermore the chosen estimation technique allows us to deal with econometric difficulties, such as measurement errors, in a straightforward manner. Finally, we do not have to make arbitrary assumptions regarding the distribution of the shocks and the errors as we would have to make if we had adopted a maximum-likelihood estimation method.

It turns out that exploring the time-series properties of series of factor demands is indispensable for the purpose of selecting moment conditions that yield precise estimates. We found that R&D capital, physical capital and labor follow an AR(3)-process with a unit-root. The first differenced series of R&D capital is near a random walk, while the differenced series of the other inputs exhibit moderate autoregressive behavior. If we would have followed common practice for estimating dynamic equations with panel data and first differenced all equations [3], the parameter estimates would have been very imprecise. Therefore we resort to the approach suggested by Arellano and Bover (1990) that is based on using differenced series as instruments.

This chapter is organized as follows. In section 2 the entrepeneur's optimization problem is formulated. Next factor demand equations are derived that allow for the heterogeneity of the firms. Section 3 examines the statistical properties of the data and describes the estimation strategy. The empirical results are discussed in section 4. Furthermore we present summary statistics on the dynamics of factor demand. Section 5 concludes.

2.2 The factor demand model

In this section the decision rules of the entrepeneur are derived for setting the levels of both physical capital K and knowledge capital G and of employment N. These rules follow from maximization of the expected discounted present value of the cash flows over the future. Adjustments of the levels of the production factors are considered costly. Futhermore it is assumed that there is a lag between the decision to invest and the moment the new capital becomes productive. That is, time is needed to build new capital, to develop new products or to acquire knowledge. In forming expectations the entrepreneurs are assumed to be rational. The information set that will be exploited includes at least current and past information about the state of the firm, i.e. the size of the stocks of both kinds of capital and the number of people employed, about factor prices and output prices and the latest news about technological opportunities. Real factor costs, that is factor prices deflated by the producer's price of output, are not influenced by the

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[3] Since the adjustment cost specification depends on first differences, the series are sometimes differenced twice.

decisions of the firm. The production technology exhibits the usual characteristics — $(\partial Y_t/\partial X_t) \geq 0$, where $X'_t = [G_t, K_t, N_t]$ and Y_t denotes real output, $\partial^2 Y_t/\partial X_t^2$ is a negative (semi-)definite matrix — and is locally approximated by a quadratic function [4]

$$Y_t = (\mu_t + a)'X_t - \tfrac{1}{2} X'AX_t \tag{2.1}$$

where μ_t [5] is a vector of exogenous technology shocks, a is a vector of constants and A is a symmetric matrix. For the adjustment costs we adopt the specification in Kollintzas (1985)

$$AC_t(G_t, K_t, N_t, \Delta G_{t+1}, \Delta K_{t+1}, \Delta N_{t+1}) = X'_t D\Delta X_{t+1} + \tfrac{1}{2} \Delta X'_{t+1} B\Delta X_{t+1} \tag{2.2}$$

where B is a positive definite symmetric matrix and D is a general matrix. When D = 0 the adjustment costs of a firm are external and strongly separable from the levels of the inputs, and convex. Note that labor is also a quasi-fixed factor.

According to Pakes and Schankerman (1978) R&D depreciates like physical capital : for both types of capital a linear depreciation scheme is specified

$$G_t = (1-\delta^G)\, G_{t-1} + s^G_{1,t} \qquad 0 < \delta^G < 1 \tag{2.3a}$$

$$K_t = (1-\delta^K)\, K_{t-1} + s^K_{1,t} \qquad 0 < \delta^K < 1 \tag{2.3b}$$

$s^G_{1,t}$ and $s^K_{1,t}$ are the gross changes in period t of effective R&D and physical capital, respectively. They result from investment projects that were started θ_G and θ_K periods ago respectively. The capital is built according to fixed plans. It is assumed that capital under construction does not depreciate. The

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[4] Leaving out the subscript i referring to firm i, for the time being.

[5] $\mu_t = (\mu_{Gt-\theta_G}\ \mu_{Kt-\theta_K}\ \mu_{Nt})'$. The technology shocks affect the quality of the inputs and should not be interpreted as indicators of the quality of the management. Therefore the timing of the shocks coincides with the last opportunity to change the corresponding stocks and to adopt thereby the latest technological innovations. θ_G and θ_K are the orders of the gestation lags that will be introduced below.

investment process for both kinds of capital is framed in the following equations

$$I_t^F = \sum_{j=1}^{\theta_F+1} \psi_j^F \, s_{j,t}^F \qquad F \in \{ G,K \} \qquad (2.4a)$$

$$s_{j,t}^F = s_{j+1,t-1}^F \qquad j = 1,2,\ldots,\theta_F \qquad (2.4b)$$

and

$$\sum_{j=1}^{\theta_F+1} \psi_j^F = 1 \qquad 0 \le \psi_j \le 1 \qquad (2.4c)$$

where $s_{j,t}^F$ is the total size of current investment projects of type F which are j periods from completion. The ψ_j^F's reflect the scheme of the building process and are the same for all investments. At the j-th stage from delivery $\psi_j \times 100$ % of the total costs involved are invested in a project. The total amount of funds invested in period t, I_t^F , is spent on projects of different age. Variable costs are given by

$$VC_t = p_t^G I_t^G + p_t^K I_t^K + p_t^N N_t \qquad (2.5)$$

where $[p_t^G \; p_t^K \; p_t^N]'$ is the vector of real factor prices at time t. The variable cost function can be formulated in terms of the stock variables. Note that $s_{j,t}^F = s_{1,t+j-1}^F$. Combining (2.3), (2.4a) and (2.4b) yields

$$I_t^F = \sum_{j=1}^{\theta_F+1} \psi_j^F \, (F_{t+j-1} - (1-\delta^F) \, F_{t+j-2}) = \sum_{j=0}^{\theta_F+1} \Psi_j^F \, F_{t+j-1} \qquad (2.6)$$

$$F \in \{ G,K \}$$

where

$$\Psi_0^F = -(1-\delta^F) \, \psi_1^F$$

$$\Psi_j^F = \psi_j^F - (1-\delta^F)\psi_{j+1}^F \qquad j = 1,2,\ldots,\theta_F$$

$$\Psi_{J+1}^F = \psi_{J+1}^F$$

From substitution of (2.6) in (2.5) it follows that

$$VC_t = p_t^G \left[\sum_{j=0}^{\theta_G+1} \Psi_j^G \, G_{t+j-1} \right] + p_t^K \left[\sum_{j=0}^{\theta_K+1} \Psi_j^K \, K_{t+j-1} \right] + p_t^N N_t \qquad (2.7)$$

The firm's objective function is

$$PV_t = \lim_{H \to \infty} E_t \sum_{h=0}^{H} \gamma^h [Y_{t+h} - VC_{t+h} - AC_{t+h}]. \quad 0 < \gamma < 1 \qquad (2.8)$$

where γ is the real discount factor and $E_t(\ ) = E(\ |\Omega_t)$ the expectation operator conditional on information until time t . The entrepeneur maximizes PV_t with respect to the decision variables N_{t+h}, $G_{t+\theta_G+h}$ and $K_{t+\theta_K+h}$, h = 0,1,2,... .

An optimal plan necessarily satisfies the first-order conditions of this problem : the Euler-Lagrange equations [ELC]

$$E_{t-\theta_F}\{-[A_{F.} - D'_{.F} + \gamma^{-1}D'_{.F}]X_t - \gamma^{-1}[B_{F.} - D'_{.F}]\Delta X_t + [B_{F.} - D_{F.}]\Delta X_{t+1}\} + a_F$$

$$+ \mu_{Ft-\theta_F} - \sum_{j=0}^{\theta_F+1} \Psi_j^F \gamma^{-j+1} E_{t-J}(p^F_{t-j+1}) = 0 \qquad F = G,K,N \ ^{6} \qquad (2.9)$$

In Kollintzas (1985) conditions are discussed that guarantee a unique, stable solution when the model is symmetric, that is when $D = D'$ [7]. Kollintzas (1986) deals with the nonsymmetric case [8].

There is a number of features of these equations that should be noted. The factor demand relations allow for many different kinds of behavior. In particular recursive interrelations, which are said to exist when past stocks of one factor of production affect the current marginal product and/or marginal adjustment costs of another factor of production, are brought about by B or D nondiagonal. Interesting comparative dynamics properties are implied by such interrelations [9]. When $D \neq D'$ the model can account for asymmetric adjustment costs due to net changes in the quasi-fixed factor stocks. In this case endogenous cycling can occur. Asymmetry can also show up in the information that is used for decisions on the inputs. That is the entrepeneur

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[6] $\Psi_0^N = 1$, $\Psi_1^N = 0$ and $\theta_N = 0$.

[7] See Kollintzas (1985), especially Corollary 2. Putting the model above with θ_G=0 and θ_K=0 in the format of his article, R = -D , Q = -A and S = -B. If the stability condition is satisfied, the model has a unique solution.

[8] In chapter 3 it is shown that stability implies uniqueness of the solution not only in the case where θ_G=0 and θ_K=0 but generally also when there is time-to-build.

[9] See Cassing and Kollintzas (1991) for a discussion and references.

decides on the size of the stock G_t on the basis of the information available at time $t-\theta_G$, which does not include the values of K_t and N_t, but the entrepreneur knows the sizes of G_t and K_t when he determines N_t.

In chapter 3 a procedure is proposed to obtain a (semi) closed form solution for the model above with $D = D'$. In that case the adjustment parameters are equal to those in the flexible accelerator form that corresponds to the model that assumes absense of the gestation lags as well. The reason for this is the fact that the characteristic polynomial of the model with time-to-build encompasses the one associated with the model that only accounts for adjustment costs. Since this also holds true when allowance is made for asymmetric ($D \neq D'$) behavior, the matrix of adjustment parameters for the model above can more easily be obtained by neglecting the time-to-build feature and working along the lines of Cassing and Kollintzas (1991) [10].

By introducing the stock of R&D capital in the model the technological evolution of the firm has been modeled explicitly. The total R&D lag θ_G consists of the time devoted to applied research and specification (the gestation lag in a narrower sense) and the time involved in manufacturing and marketing start-up (the application lag). Wagner (1968) provides information on both lags. For the first lag he presents a number somewhat higher than one (year). During this period it will become clear whether a project is successful. If so, the second stage takes off. Since the success will generally also induce ordinary investment, this stage of the innovation process is expected to be closely connected to the building of physical capital. The average application lag calculated by Wagner is one year for nondurables and one and a half year for durables. Mayer (1960) provides survey results on the gestation lag for physical capital. He found that there was a lag of somewhat more than two years involved in building plants and of about two quarters in the construction of equipment. Since the latter forms the larger part of the

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[10] Let $\Delta = B - D$ and $\Gamma = A + \frac{1+\gamma}{\gamma} B - D - D'$. Then $E(\lambda) = \Delta\lambda^2 - \Gamma\lambda + \gamma^{-1}\Delta'$ is the characteristic polynomial for the model without time-to-build. Further let $K = \mathrm{diag}(K_1,\ldots,K_l)$ where K_i is the Jordan block corresponding to eigenvalue λ_i ($|E(\lambda_i)| = 0$) and let $M = [M_1,\ldots,M_l]$ where M_i is a matrix with (generalized) eigenvectors of $E(\lambda)$ corresponding to λ_i. Then $T = I - MKM^{-1}$ is the matrix of adjustment parameters in a flexible accelerator representation of the solution.

capital stock it seems reasonable to assume an average gestation lag for physical capital of approximately one year. The model can rationalize cointegration between the production factors, especially between both kinds of capital.

The model that was derived above is not sufficiently flexible for estimation purposes. In order to cope with the heterogeneity among firms both the production function and the adjustment cost function will be generalized. For the first function this will be done by substituting expressions for the parameters that are derived under the hypothesis that a Cobb-Douglas technology is approximated. Thus if actually

$$Y_{it} = \alpha_0 G_{it}^{\alpha_{Gi}} K_{it}^{\alpha_{Ki}} N_{it}^{\alpha_{Ni}} \tag{2.10}$$

holds, it follows that the coefficients in the second order Taylor approximation (2.1) around (Y_{i0}, X_{i0}) satisfy

$$a_{Fi} \approx \frac{Y_{i0}}{X_{Fi0}} (\alpha_{Fi} - \alpha_{Fi} [\alpha_{Gi} + \alpha_{Ki} + \alpha_{Ni} - 1]) \quad F = G,K,N \tag{2.11a}$$

$$a_{FHi} \approx - \frac{Y_{i0}}{X_{Fi0} X_{Hi0}} \alpha_{Fi} (\alpha_{Hi} - \delta_{FH}) \; F,H = G,K,N \; \delta_{FH} = 1 \text{ if } F = H \tag{2.11b}$$
$$= 0 \text{ if } F \neq H$$

As long as the technology does not exhibit increasing returns to scale, that is when $\alpha_G + \alpha_K + \alpha_N \leq 1$ holds, the expressions in (2.10) are consistent with the convexity of A. These formulae identify the sources of the heterogeneity in the parameters of (2.1). From several studies, e.g. see Pakes and Schankerman (1984) and Mairesse and Griliches (1990), it is known that factor intensities and elasticities can differ widely among firms. Since maximization of the value of the firm implies that in the stationary state the factor elasticities equal the cost shares, the a_{FH}'s are expected to be correlated with the corresponding variables in the Euler equations. Then the use of a random effects estimator would lead to erroneous results. If interest is primarily focused on the parameters of the adjustment cost function, the equalities mentioned above can be used to get rid of the production function parameters. Alternatively one can employ a fixed effect estimator. To avoid a burdensome computation problem we will choose the first approach. Because the

model is essentially a disequilibrium model it seems appropriate to appeal to a more loose relationship between the elasticities and the cost shares

$$\alpha_{Fi} = \vartheta_{F1} + \vartheta_{F2} p_0^F \frac{X_{Fi0}}{Y_{i0}} \quad [11] \qquad F = G,K,N \tag{2.12}$$

Substituting these formulae leads at most to 3 regressors associated with the diagonal parameters a_{FF} and to 4 regressors associated with the other a_{FH}'s.

A specification for the adjustment costs that is expected to accommodate to the heterogeneity is one in relative changes [12] [13]

$$AC_{it}(\Delta G_{it+1}, \Delta K_{it+1}, \Delta N_{it+1}, G_{it}, K_{it}, N_{it}, Y_{i0}, G_{i0}, K_{i0}, N_{i0}) = \tag{2.13}$$

$$\tfrac{1}{2} Y_{i0} \left[\frac{\Delta X_{it+1}}{X_{i0}} \right]' \tilde{B} \left[\frac{\Delta X_{it+1}}{X_{i0}} \right] + Y_{i0} \left[\frac{X_{it}}{X_{i0}} \right]' \tilde{D} \left[\frac{\Delta X_{it+1}}{X_{i0}} \right]$$

$$\text{where} \quad \left[\frac{X_{it}}{X_{i0}} \right] \equiv \left[\frac{G_{it}}{G_{i0}}, \frac{K_{it}}{K_{i0}}, \frac{N_{it}}{N_{i0}} \right]'$$

This function is homogeneous of degree one [14] in all the variables it depends on, whereas according to (2.2) there are increasing costs to scale as far as they are related to the adjustment process. Firm data can be thought of as the result of aggregating plant data. As Gordon (1992) points out, by employing a specification that is linear homogeneous, the use of firm data will not yield (downward) biased estimates of the adjustment cost parameters due to aggregation. Since the paths of the solutions to both models are locally similar, specification (2.13) can be replaced by (2.2) in order to study the local stability properties of the model.

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[11] For F = G,K, ϑ_{F2} includes the factor $(r-\pi+\delta^F)$, where r is the nominal interest rate and π is the inflation rate.

[12] The nought refers to a base period.

[13] This specification is related to that in (2.2) : B is replaced by $B_i = [b_{FH}]_i$ with $b_{FHi} = \delta_{FH} Y_{i0} / X_{Fi0} X_{Hi0}$. Likewise for D.

[14] This property should be considered from a cross-section perspective.

2.3 Data and estimation strategy

The data we used to estimate the factor demands are taken from the Manufacturing Sector Master File panel which is assembled by Hall (1990a). The panel is mainly based on Compustat data. The firms in our sample are from five industries in the so-called scientific sector: Chemicals excluding drugs (SIC 28 \ 283), Drugs (283), Office and Computing Machines (SIC 357), Electric and Electronic equipment (SIC 36) and Instruments and Related Products (SIC 38). As might be expected these industries have the highest R&D intensities. The largest data set we use in this study covers the period 1959-1987. Because most firms did not exist the whole period the design of our samples is unbalanced. Firms that experienced major changes were eliminated from the panel. The data sets were limited further by requiring that a significant part of the firm's resources is spent on R&D. Information on producer prices and for the construction of wages was obtained at the 3-4 digit SIC industry level. The deflators for fixed investment also pertain to the industry level but the R&D deflator was obtained at the most aggregate level. The construction of the variables and the trimming of the dataset are described in more detail in Appendix 2.B. A table with descriptive statistics has been relegated to Appendix 2.B too.

Absence of time-to-innovate is an assumption that is implicit in the way the R&D capital stock series is constructed. This is conflicting with our model. Assuming $\theta_G=2$ and a uniform investment scheme ($\psi^G_i=0.33$, i=1,2,3) and noting that the variability in R&D stock series is rather low, G_t in the model can be proxied by the lagged value of the constructed series in the data base. The measurement of physical capital is hampered by a similar problem: only the book value at the end of the (fiscal) year is observed which includes expenditures for capital goods that are still unfinished. If the gestation lag is one year, the stock of physical capital that can be used for production is assumed to equal the (properly deflated) lagged net book value adjusted for inflation.

It is not feasible to derive a closed form solution for the Euler equations that are associated with the specifications of the production function and the adjustment cost function that take the heterogeneity among firms into account. Therefore they have been estimated directly by applying

the GMM estimator. The parameters of the Euler equations [15] are first order strongly identifiable so this estimator is strongly consistent [16]. Application of the asymptotic least squares estimation method which exploits the nonlinear and cross equation restrictions between these parameters and the structural parameters yields estimates for the latter.

For the choice of the instruments or more generally the moment conditions if one brings in the possibility to transform the equations before estimating them, it is important to consider the properties of the data. The issue of heterogeneity has already been raised. Even after the respecification some permanent effects could still be left in the errors of the equations. Measurement error is another well-known problem with the type of data used in this study. However permanent mismeasurement of the stocks of the multiplicative variety, i.e. the scale of the stocks, is less of a problem since our analysis is relative to some recent state of the firm.

Knowledge of the time series properties can also be instrumental for selecting suitable moment conditions. These properties have been investigated in the case of all factors of production. Univariate autoregressive schemes were fitted to the series employing an IV estimator. The enormous differences in firmsize would bias results towards finding a unit root. Therefore the series were scaled by sales or the first observation of the stock of the input. The latter procedure is preferred since R&D intensities still differ substantially among firms. To avoid inconsistency of the estimates due to fixed effects in the form of individual intercepts, the regression equations were differenced. Second and higher lags of the series (also scaled) were used as instruments. If there were no fixed effect but a unit root, differencing would remove that root. Therefore results should be interpreted carefully. The main results are summarized in table 1. (When sales was used for scaling the observations similar results were obtained). All three series can be described well by an AR(3)-proces. Furthermore R&D seems to have at least one unit root. To investigate the presence of a unit root in more depth, we also pursued an alternative approach.

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[15] Formally these parameters are called structural parameters too. But this terminology is preferably used for the parameters in the model, such as the adjustment cost function parameters b_{FH}.

[16] For a definition of first order strongly identifiable see Broze, Gouriéroux and Szafarz (1991b).

Breitung and Meyer (1991) constructed a test on unit roots in a panel data context allowing for fixed effects under the alternative. The idea is to deal with the individual effects by subtracting the first observation from the series for every firm in the panel. Table 2 contains the estimation results obtained for these equations. They confirm the existence of the unit root in the series of R&D capital. For labor and physical capital the unit root hypothesis could not be rejected either. Estimation of the AR models in levels with first differences as instruments also produces the unit roots for all series and a second unit root for R&D. That is ΔG (almost) follows a random walk. The correlation between the first differences of physical capital and the lagged first differences is moderate. The same is true for labor.

Our results for the time series properties of the stock of R&D are consistent with the fact that the stock has been constructed using the rule $G_t = (1-\delta^G)G_{t-1} + R_t$ with $\delta^G = 0.15$ and the finding of Hall, Griliches and Hausman (1986) that $\log R_t$ follows an AR process of a low order with a (close to) unit root.

Because the R&D capital series are almost second-order integrated, taking first-differences of the Euler equations before estimating them leads inevitably to low correlation between some of the RHS-variables, namely those related to the adjustment costs, and the instruments and as a consequence imprecise estimates can be expected.

Table I

Univariate Analysis of Time Series Behavior

Δy_{it}	Δy_{it-1}	Δy_{it-2}	Δy_{it-3}
ΔG_{it}	0.810 (0.048)	0.238 (0.056)	0.024 (0.028)
ΔK_{it}	0.832 (0.087)	-0.018 (0.050)	-0.084 (0.023)
ΔN_{it}	0.717 (0.083)	-0.229 (0.040)	-0.140 (0.018)

instruments y_{it-2} y_{it-3} y_{it-4}

all variables are scaled by y_{i1}

1973-1987, #Obs. 1533, #Firms 193

standard errors are shown in parentheses

Table II

Breitung - Meyer Tests on Unit Roots

$\bar{\Delta}y_{it}$	$\bar{\Delta}y_{it-1}$	$\bar{\Delta}y_{it-2}$	$\bar{\Delta}y_{it-3}$
$\bar{\Delta}G_{it}$	2.202 (0.032)	-1.287 (0.055)	0.084 (0.026)
$\bar{\Delta}K_{it}$	0.945 (0.018)	0.392 (0.027)	-0.282 (0.024)
$\bar{\Delta}N_{it}$	1.247 (0.017)	-0.119 (0.027)	-0.079 (0.021)

$\bar{\Delta}y_{it}$: long-differences of y_{it}, i.e. y_{it}-y_{i1}
instruments $\bar{\Delta}y_{it-1}$ $\bar{\Delta}y_{it-2}$ $\bar{\Delta}y_{it-3}$
all variables are scaled by sales
1973-1987, # Obs. 1533, # Firms 193
standard errors are shown in parentheses

Since the R&D intensity of firms does not vary as much over time as the intensities of the other inputs and because of the presence of gestation lags, that prevent the use of low lags of some of the endogenous variables as instruments, the problem will be most severe when estimating the R&D equation.

Alternatively in order to avoid inconsistency as a result of neglecting heterogeneity in the intercept one can use instruments that are functions of the first differences of the variables (see Arellano and Bover (1990)). The correlation between such instruments and the regressors will be much higher in the case of the R&D equation.

Apart from measurement error and the individual effect, the error term of the equations includes forecast errors and a technology shock, which is by assumption white noise. Depending on whether the technology shocks are contemporaneously correlated or not, the error terms can be modeled as MA(θ_F+1) or MA(θ_F) [17] where θ_F equals the duration of the time-to-build of the inputs [18]. We identify the orders of the gestation lags of the capital stocks empirically by testing the validity of instruments of decreasing order of the lags.

[17] The error term contains a MA(1) process if there is no gestation lag.

[18] In Appendix 2.A, we show how the orders of the moving average processes, that are implied by the model assumptions, have been determined.

The considerations above motivate the estimation of the R&D Euler equation in levels and both other equations in first differences making use of the instruments listed in Appendix 2.C. In order to obtain optimal GMM estimates Hansen (1982) has shown that the weighting matrix has to be replaced by a consistent estimator of the inverse of the covariance of the sample moments which appear in the conditions that are the keystone of this estimation strategy. Since the error term of the R&D equation contains a permanent individual effect we assume autocorrelation of maximum order when computing the weighting matrix. The order of the autocorrelation varies with the number of observations for the individuals due to the fact that the panel is unbalanced. In this case it can be shown that the weighting matrix is positive definite [19] [20].

In general, when the simple covariance estimator is not positive definite, neglecting null restrictions on the autocorrelations of the errors, implied by the theoretical model, when computing an estimate of the covariance matrix by assuming autocorrelations of maximum order, seems a good alternative to the Newey and West method. The resulting estimator has the advantage that its consistency depends only on the number of individuals in the panel.

For different choices of the point of approximation (indexed with the nought) we obtain different models. When we choose last period (t-1) as the base period the number of regressors per equation is three less than for any other choice. For the general case the restrictions between the structural parameters we are interested in and the Euler equation parameters can be found

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[19] The simple covariance matrix is a consistent estimator but in general not necessarily positive definite. Using such an estimator may be troublesome. In the time series literature several alternatives to this estimator have been proposed that do not suffer from the defect mentioned above, e.g. see Newey and West (1987). They suggest to use a Bartlett kernel to smooth the autocovariances. But in general the conditions for consistency are not fulfilled in an (unbalanced) panel context, where the number of waves is typically low.

[20] For this purpose it is convenient to stack the systems of equations for different periods. In this framework one individual contributes one vector observation, which also contains zeros when the individual did not exist all the time. The proposed estimator of the covariance matrix is obtained by allowing for correlation between all sample moments corresponding to the system that results from stacking. Observe that this estimator is the sum of many rank 1 matrices that are equal to a vector (corresponding to one observation) multiplied by its transpose. Generally when the number of individuals exceeds the number of moment conditions, the covariance matrix will be of full rank.

in Appendix 2.D [21]. When t-1 is chosen as the point of approximation the first four restrictions associated with ζ_1 till ζ_4 should be added up. Apart from the time preference parameter γ, which can always be identified, the structural parameters can only be identified by adding a restriction on, for instance, one of the diagonal elements of B-D [22]. When we approximate the technology in the neighborhood of the last data point (t-1) the structural parameters are exactly identified. But in the general case the structural parameters are overidentified, which opens up the possibility to test the model by performing a (Generalized) Wald test. In the case that last period is the base period one can still test whether the time preference parameter assumes a reasonable value. Furthermore one can test whether the estimates satisfy theoretical conditions such as B is positive definite symmetric.

2.4 Empirical results

All results reported in this section pertain to the 1967-1986 period. Furthermore last year (t-1) is taken as point of approximation in the model. As prices and wages are the driving forces in the Euler equations, it is important to measure them as accurately as possible. Therefore we have used information from the productivity database from NBER, which contains series at the four digit SIC industry level of aggregation. However for many industries no satisfactory information was available and this lead to the exclusion of quite a number of firms from our panel (about 58%).

Before we can present the estimation results, we have to assess the length of the time-to-build periods of R&D and physical. This boils down to testing the validity of the instruments used and the significance of the lags of the prices. As mentioned in the last section, when the technology shocks are contemporaneously correlated, the order of the MA process in the error term increases by one. From knowledge of the highest significant lag of the

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[21] We have only included those obtained for the Euler equation of R&D. The other restrictions can be obtained by exploiting that the model is symmetrical in the inputs.

[22] Define $f_{FH} = b_{FH} - d_{FH}$ $F \leq H$ (assuming $G < K < N$) and $g_{FH} = (1-\gamma)d_{FH} - \gamma\vartheta_{F1}\vartheta_{H1}$. After substituting these parameters for the b_{FH}'s and the d_{FH}'s it is easily seen that given γ the RHS of the restrictions are homogeneous of degree zero.

price and information on the order of the MA process we can infer the order of the gestation lags and whether the technical shocks are correlated. Table 3 displays the Sargan test statistics on the validity of the moment conditions for different Euler equations (f.o.c.'s associated with different factors of production) and for different values of the orders of the gestation lags [23].

Table III

Sargan Tests

θ_F	G	K	N
0	n.c.	1.77(4)	7.44(7)
1	n.c.	3.86(8)	n.c.
1TC	12.16(4)	2.26(4)	n.c.
2	6.25(8)	2.38(4)	n.c.
2TC	2.77(4)	n.c.	n.c.

period: 1967-1986, 104 firms, 802 observations
optimal HAC weighting has been used
TC means technical shocks are correlated, n.c. stands for not computed, d.o.f. between parentheses
$\chi^2_{0.95}(4) = 9.49$, $\chi^2_{0.95}(7) = 14.07$, $\chi^2_{0.95}(8) = 15.51$

First of all the test results indicate that at least for one choice of the orders of the gestation lag the model is adequately specified. Furthermore they suggest a time-to-build period of two years for R&D and at most one year for physical capital. These results are in line with the information on this matter given by Mayer and Wagner. Notice that the values of the test statistics for the model without correlation of technical shocks are well below the critical values. By looking at differences of test statistics, which are Sargan difference tests, we can test the presence of correlation among the technical shocks in isolation. However we still cannot reject the absence of correlation.

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[23] Under the null hypothesis of valid instruments the test statistic is asymptotically distributed as a χ^2- statistic with d.o.f. equal to the number of instruments minus the number of estimated parameters. Time dummies were included in the equations that were estimated to cope with aggregate shocks.

Table IV **GMM Estimates of Euler Equations**

R&D		PHYS. CAPITAL		LABOR	
$Y_{-1}(G_{+1}-G)/G_{-1}G_{-1}$	dep. var.	$Y_{-1}(K_{+1}-K)/K_{-1}K_{-1}$	dep. var.	$Y_{-1}(N_{+1}-N)/N_{-1}N_{-1}$	dep. var.
G/Y_{-1} p^G p^G	-1.685 (12.69)	K/Y_{-1} p^K p^K	0.186 (0.146)	N/Y_{-1} p^N p^N	24.25 (29.31)
Y_{-1}/G_{-1}	0.026 (0.168)	Y_{-1}/K_{-1}	0.002 (0.031)	Y_{-1}/N_{-1}	0.031 (0.039)
$Y_{-1}(G-G_{-1})/G_{-1}G_{-1}$	0.936 (0.487)	$Y_{-1}(K-K_{-1})/K_{-1}K_{-1}$	1.001 (0.179)	$Y_{-1}(N-N_{-1})/N_{-1}N_{-1}$	1.778 (1.138)
$Y_{-1}(K_{+1}-K)/K_{-1}G_{-1}$	0.210 (0.244)	$Y_{-1}(G_{+1}-G)/G_{-1}K_{-1}$	-0.657 (0.446)	$Y_{-1}(G_{+1}-G)/G_{-1}N_{-1}$	3.685 (4.200)
$Y_{-1}(K-K_{-1})/K_{-1}G_{-1}$	0.135 (0.173)	$Y_{-1}(G-G_{-1})/G_{-1}K_{-1}$	0.580 (0.411)	$Y_{-1}(G-G_{-1})/G_{-1}N_{-1}$	-3.586 (4.171)
K/Y_{-1} p^G p^K	0.213 (2.765)	G/Y_{-1} p^G p^K	-0.129 (0.167)	G/Y_{-1} p^G p^N	0.701 (1.374)
$Y_{-1}(N_{+1}-N)/N_{-1}G_{-1}$	-0.378 (0.323)	$Y_{-1}(N_{+1}-N)/N_{-1}K_{-1}$	-0.138 (0.345)	$Y_{-1}(K_{+1}-K)/K_{-1}N_{-1}$	0.287 (0.301)
$Y_{-1}(N-N_{-1})/N_{-1}G_{-1}$	-0.379 (0.255)	$Y_{-1}(N-N_{-1})/N_{-1}K_{-1}$	0.829 (0.375)	$Y_{-1}(K-K_{-1})/K_{-1}N_{-1}$	-0.993 (0.810)
N/Y_{-1} p^G p^N	10.92 (47.54)	N/Y_{-1} p^K p^N	1.007 (1.269)	K/Y_{-1} p^K p^N	-0.232 (1.163)
p^G_{-2}	-0.526 (5.305)	p^K_{-1}	-4.767 (3.095)	p^N	-0.797 (3.552)
p^G_{-1}	14.12 (22.92)	p^K	-5.289 (4.477)		
p^G	-26.51 (32.81)	p^K_{+1}	0.977 (2.003)		
p^G_{+1}	11.97 (18.81)				
m_1	0.114	m_1	-1.113	m_1	-2.044
m_2	0.612	m_2	-0.473	m_2	-0.912

Period: 1967-1986, 802 observations, 104 firms, unbalanced design. HAC standard errors between parentheses. Time dummies have been included. m_1/m_2 robust test for 1st/2nd order serial correlation ~ N(0,1).

Table V

Specification Tests

H_0	H_1	distr.	test (p-value)
$f(b,\zeta)=0$, $D=0$	$\neq 0$, $D=0$	$\chi^2(9)$	21.30 (0.015)
$f(b,\zeta)=0$, B PDS, $D=0$	$\neq 0$, B not PDS, $D=0$	$m\chi^2(3,9)$	29.24 (0.003)
$f(b,d,\zeta)=0$	$\neq 0$	$\chi^2(3)$	1.01 (0.800)
$f(b,d,\zeta)=0$, B PDS	$\neq 0$, B not PDS	$m\chi^2(3,3)$	22.70 (0.001)

period: 1967-1986, 104 firms, 802 observations
f( ) are overidentifying restrictions, $b_{KK}-d_{KK}=1$
$m\chi^2(A,B)$ is a mixed χ^2 distribution of a test statistic for A ineq. and B equality constraints under H_0, see Kodde & Palm (1986) for details

Since the models with $\theta_G=2$ and $\theta_K=1$ are not rejected, we continue our analysis with the system corresponding to these gestation lags. The null restrictions on the ϑ_{F1}'s that hold in the long run equilibrium were imposed in order to reduce the number of instruments necessary for estimation [24]. The GMM parameter estimates of the Euler equations are shown in table 4. These reduced form estimates will be evaluated in the light of their implications for the values of the parameters of the structural model. According to the structural models the Euler equation parameters are equal to ratios with the

[24] Apart from prices the instruments are lags of the endogenous regressors. As the relevance of additional lags is expected to decline, i.e. the partial correlation between instruments and regressors decreases, biases in the estimates of the parameters due to random sample fluctuations arise/increase when adding lags to the set of instruments (see Shea (1993)). The restrictions were also imposed when calculating the test statistics presented in table 3.

difference of the own adjustment cost parameters (b_{FF}-d_{FF}) in the denominator. If these differences are large as compared to the other parameters, the Euler equation parameters should be small.

Before we compute the ALS estimates that are implied by the Euler equation estimates and their covariance, tests are performed to select the most parsimonious model that describes the main features of the data in a satisfactory way. The results are given in table 5. The overidentifying restrictions that correspond to the most general model that allows for nonseparability and asymmetry among the factor demands, easily pass the test. However the joint hypothesis that the overidentifying restrictions hold as well as one of the conditions for global stability, namely B is positive definite symmetric, fails to pass the distance test described in Kodde and Palm (1986) [25]. For the simple adjustment costs model where D = 0 both the

Table VI
ALS Estimates

b_{GG}	1.052 (0.597)	b_{GK}	0.183 (0.101)
b_{KK}	0.362	b_{GN}	0.244 (0.142)
b_{NN}	-0.272 (0.230)	b_{KN}	0.121 (0.085)
γ	0.921 (0.036)	$\chi^2_{GW}(9)$	= 20.62

period: 1967-1986, 104 firms, 802 observations
standard errors between parentheses, b_{KK} was fixed
χ^2_{GW} is the generalized Wald test, $\chi^2_{0.99}(9)$=21.66

generalized Wald test (table 6) and an ordinary Wald test (table 5) for overidentifying restrictions, which are asymptotically equivalent, yield a p-value of ±0.02. A joint test of equality (overidentifying) restrictions and inequality restrictions (on the eigenvalues of B) leads to rejection of the model at a 1% level of significance. Notwithstanding these test outcomes it is worthwhile to look at the estimates obtained for the simple model. They may be helpful in finding the reasons for rejection of the structural model.

[25] The values of the test-statistics are not invariant with respect to the normalization chosen. However the qualititative results did not change when we assumed that another parameter was known.

The estimates that exploit the largest subset of the identifying restrictions given in appendix 2.D are shown in table 6 [26]. For the discount factor, that can be identified in any case, a reasonable estimate of 0.921 was obtained. However the own adjustment cost parameter of labor is negative although not significantly so. The results in tables 5 and 6 suggest that the adjustment costs function is misspecified with respect to labor. Hamermesh (1993) argues that both gross and net adjustment costs of labor are important. Furthermore in a study by Hamermesh (1989) at the plant level a lumpy adjustment cost specification fits the data better than a quadratic function . Others included the length of the workweek as well as the number of employees in their specification of the adjustment cost function.

Table VII

ALS Estimates (limited information)

b_{GG}	0.933 (0.740)	b_{GK}	0.168 (0.135)
b_{KK}	0.362		
γ	0.940	$\chi^2_{GW}(4) = 11.46$	

period: 1967-1986, 104 firms, 802 observations
standard errors between parentheses, b_{KK},γ fixed
χ^2_{GW} is the generalized Wald test, $\chi^2_{0.99}(4)=13.3$

Since we lack information needed for investigating these possibilities, we will continue the analysis abstracting from the precise adjustment cost specification for labor.

The adjustment behavior of both types of capital can still be studied in a limited information framework provided that the cross terms that involve labor are specified correctly. Reestimation of the model exploring only the

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[26] Recall that after reparameterizing the identifying restrictions between the Euler equation parameters and the structural parameters are homogenous of degree zero in the latter (apart from the discount factor). Therefore one of the parameters had to be fixed. We assume b_{KK} to be given as we can find estimates for this parameter in the literature. For other choices of the identification rule different estimates of the standard errors are obtained.

restrictions that do not involve parameters from the labor equation renders a value for γ slightly above 1. After γ was fixed at 0.94, the results in table 7 were obtained. The estimates for b_{GG},b_{GK} are now less precisely determined.

Using the estimates of the parameters in the upperleft block of B we can calculate the distribution of the adjustment costs under the assumption $\Delta N=0$. The level of the structural parameters has been chosen to yield an average of adjustment costs for physical capital comparable to that found by Pindyck and Rotemberg (1983) and Shapiro (1986a). This approach is justified by the fact that the cross-adjustments cost terms that pertain to adjustments of physical capital are economically minor. Table 8 displays the distribution and the sources of adjustment costs.

Table VIII

Relative Adjustment costs * $|\Delta N=0$

	mean	10%	median	90%
Total	0.0179	0.0008	0.0058	0.0381
R&D	0.0082	0.0002	0.0019	0.0147
Capital	0.0088	0.0006	0.0019	0.0199

* Adjustment cost as fraction of output

period: 1967-1986, 104 firms, 802 observations

The distributions of own adjustment costs of physical capital and R&D are very similar: although b_{GG} is three times as large as b_{KK} , the variance of R&D capital is about one third the variance of physical capital [27].

2.5 Conclusions

In this chapter we have estimated demand equations for labor, physical capital and R&D that were derived from a stochastic dynamic linear quadratic programming problem. The gestation lags for both types of capital were identified by testing the validity of endogenous instruments. When gestation

[27] Compare the standard deviations of $\Delta G/G_{-1}$ and $\Delta K/K_{-1}$ in appendix 2.B.

lags were taken into account, the lags of the inputs remained significant. However, joint hypothesis of convex adjustment costs for all three inputs and rational expectations is rejected. Apart form the possible reasons mentioned above, this could be due to the normalizations used when estimating the Euler equations with GMM. It is well-known from the empirical results obtained for linear-quadratic inventory models that the signs of estimates of important parameters depend strongly on the normalization used. Another possibility, of course, is that the rational expectations hypothesis does not hold.

To avoid biases in the estimates, we have paid attention to problems such as heterogeneity and the time series properties of the inputs. Although we have chosen the moment conditions under the requirement that the (a priori) expected (partial) correlation between instruments and regressors will be maximal, the precision of the ALS estimates was rather low in spite of the large number of observations. As an additional explanation, we notice that this can be expected to the extent that random variation in the slope parameters is present. Nevertheless most of the structural parameter estimates are on the verge of being significant.

As we have seen most of the identifying restrictions between the Euler equation parameters and the structural parameters are homogeneous of degree zero in the latter. In principle the relationship between the coefficients of the user cost of the inputs and some structural parameters could be exploited for the identification of absolute levels of those parameters. However to obtain reasonable estimates, it is essential to have accurate information on input prices, in particular the tax situation of the firm. Since we lacked this information we had to rely on estimates of the relative adjustment costs of physical capital from another study.

To enhance the realism (and explanatory power) of the model and to improve the conditions for identification of the parameters we could relax the assumption of infinitely elastic supply of funds at a certain opportunity rate. In practice the supply curve of funds is upward sloping for reasons as bankruptcy costs, monitoring costs, lemons premia etc. .

Appendix 2.A: The orders of the MA component of the error terms and valid instruments.

In this appendix we explain how the orders of the MA processes in the error terms of the estimating equations are determined. We will do this by considering four simplified versions of our model but of increasing complexity. The error terms in these models will exhibit the essential characteristics of the error terms of our model.

Model 1: one (endogenous) production factor y_t without a gestation lag
A simple Euler equation (first order condition) for y_t would be

$$E_t y_{t+1} = \delta_1 y_t + \delta_2 y_{t-1} + \mu_t \tag{A.1}$$

$$E_t y_{t+1} = y_{t+1} + \varepsilon^0_{t+1} \tag{A.2}$$

where the δ's are reduced form parameters, E_t denotes expectation conditional on the set Ω_t which contains information till time t. μ_t is a technology shock with $E_{t-1}\mu_t = 0$, that is observed by the manager of the firm but not oberved by the econometrician, and ε^0_t is a prediction error. More generally, we define a revision $\varepsilon^i_t \equiv E_{t-1}y_{t+i} - E_t y_{t+i}$. Substituting (A.2) in (A.1) gives

$$y_{t+1} = \delta_1 y_t + \delta_2 y_{t-1} + \mu_t - \varepsilon^0_{t+1} \tag{A.3}$$

Since $E(\mu_t \varepsilon^0_t) \neq 0$, the error term in (A.3), $\mu_t - \varepsilon^0_{t+1}$, could be modeled as a MA(1) process $w_{t+1} + \gamma_1 w_t$. Therefore (or because $E(\mu_t y_t) \neq 0$) only y_{t-1} and higher lags of y_t are valid instruments.

Model 2: one factor of production y_t with a gestation lag of order θ

$$E_{t-\theta} y_{t+1} = \delta_1 y_t + \delta_2 y_{t-1} + \mu_{t-\theta} \tag{A.4}$$

Replacing expectations by realizations and revisions and neglecting parameters in the error terms, we obtain

$$y_{t+1} = \delta_1 y_t + \delta_2 y_{t-1} + \mu_{t-\theta} - \varepsilon^{\theta}_{t+1-\theta} \tag{A.5}$$

Since $E(\mu_{t-\theta}\varepsilon^{\theta}_{t-\theta}) \neq 0$ but $E_{t-2-\theta-i}(\mu_{t-\theta}\varepsilon^{\theta}_{t-1-\theta-i}) = 0 \ \forall\ i \geq 0$, the error term in (A.5) follows a MA(1) process. Note that since $y_{t-1} \in \Omega_{t-\theta-1}$, $E_{t-\theta-1}(\varepsilon^{\theta}_{t+1-\theta}y_{t-1}) = 0$ and $E_{t-\theta-1}(\mu_{t-\theta}y_{t-1}) = 0$, which means that y_{t-1} and lags of y_t of higher order are valid instruments.

Model 3: two factors of production y_{1t}, y_{2t}; the first is built with a gestation lag of order θ; the technology shocks μ_{1t}, μ_{2t} are uncorrelated

$$E_{t-\theta}y_{1,t+1} = \delta_{11}y_{1,t} + \delta_{12}y_{1,t-1} + \mu_{1,t-\theta} + E_{t-\theta}\delta_{20}y_{2,t+1} + E_{t-\theta}\delta_{21}y_{2,t} + E_{t-\theta}\delta_{22}y_{2,t-1} \tag{A.6}$$

Replacing expectations by realizations and revisions and neglecting parameters in the error terms, yields

$$y_{1,t+1} = \delta_{11}y_{1,t} + \delta_{12}y_{1,t-1} + \delta_{20}y_{2,t+1} + \delta_{21}y_{2,t} + \delta_{22}y_{2,t-1} + \mu_{1,t-\theta} - \varepsilon^{\theta}_{1,t+1-\theta} - \sum_{i=0}^{\theta}\varepsilon^{i}_{2,t+1-i} - \sum_{i=0}^{\theta-1}\varepsilon^{i}_{2,t-i} - \sum_{i=0}^{\theta-2}\varepsilon^{i}_{2,t-1-i} \tag{A.7}$$

Since $E_{t-\theta-1}(\mu_{1,t-\theta}y_{1,t-\theta}) = 0$ and $E_{t-\theta-1}(\mu_{1,t-\theta}y_{2,t-\theta}) = 0$, and since $y_{1,t-\theta}$ and $y_{2,t-\theta}$ are orthogonal to the revisions by definition, the error term could be modeled as a MA(θ) process. $y_{1,t-1}$ is still a valid instrument because it is also uncorrelated with revisions with respect to the second input (remember $y_{1,t-1} \in \Omega_{t-\theta-1}$). The lowest lags of y_1 and y_2 that can serve as instruments are $y_{1,t-1}$ and $y_{2,t-\theta}$.

Model 4: two factors of production y_{1t}, y_{2t}; the first is built with a gestation lag of order θ; the technology shocks μ_{1t}, μ_{2t} are correlated

We have the same equations as (A.6) and (A.7), but from $E(\mu_{1,t-\theta}\mu_{2,t-\theta}) \neq 0$ and $E(\mu_{2,t-\theta}y_{2,t-\theta}) \neq 0$, it follows that $E(\mu_{1,t-\theta}y_{2,t-\theta}) \neq 0$ and $E(\varepsilon^{0}_{2,t-\theta}\mu_{1,t-\theta}) \neq 0$. Thus the error term follows a MA(θ+1) process. The lowest lags of y_1 and y_2 that can serve as instruments are $y_{1,t-1}$ and $y_{2,t-\theta-1}$.

General remark: since Y_t (output) depends on inputs that have no gestation lags, the same lags of Y_t are valid instruments as those lags of such an input that can be used as instruments.

Appendix 2.B: Data sources * and construction of variables

$\tilde{p}$ Value of shipments deflator from BEA and BLS (3-4 digit level SIC, see BG)

$\tilde{p}^G$ Deflator for R&D capital constructed as the weighted average of an index of hourly labor compensation and the implicit price deflator in the non-financial corporate sector. (U.S. Dept. of Labor) Only one series for the whole manufacturing sector (1 digit level SIC, see also Hall (1990a)).

p^G $= \tilde{p}^G/\tilde{p} \times 100$: real costs of investments in knowledge capital.

$\tilde{p}^K$ price deflator for new fixed investment (3-4 digit SIC, see BG)

p^K $= \tilde{p}^K/\tilde{p}$: real costs of investments in physical capital.

$\tilde{p}^N$ Hourly wage rate calculated on the basis of information from Annual Survey of Manufactures from Census Bureau (4 digit SIC, see BG).

p^N $= \tilde{p}^N/\tilde{p} \times 100$: real wage.

G The stock of R&D capital, constructed from the history of R&D investment using a perpetual inventory model with declining balance depreciation. See also Hall (1990a). G is the RSTOCK series taken from the MSMF** panel deflated by $\tilde{p}^G$.

K The inflation adjusted net capital stock. K is the NPLANT series taken from MSMF deflated by $\tilde{p}^K$.

N Labor force calculated as $N = L \times H \times 0.01$ where
L is the number of employees in the firm : EMPLY taken from MSMF
H is weekly hours of work in the industry (ASM, 4 digit SIC, see BG)

Y Output calculated as $Y = S + \Delta Inv$ where
S is net sales : SALES taken from MSMF
ΔInv is the change in the value of the firm's inventories adjusted for the effects of inflation : (Δ)ADJINV taken from MSMF.

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* : For a description of the productivity database from NBER see Bartelsman and Gray (1994), abbreviated as BG.

** : Manufacturing Sector Master File (B.H. Hall (1990a)).

Trimming Values *

Variable	Description	Minimum	Maximum
I_t/K_t	Investment-Capital ratio	0.001	0.50
R_t/K_t	R&D-Investment-Capital ratio	0.001	0.35
G_t/K_t	R&D-Capital ratio	0.001	2.00
Y_t/K_t	Sales-Capital ratio		10.0
$\Delta G_t/G_{t-1}$	R&D Net Investment-Capital ratio	-0.60	1.20
$\Delta K_t/K_{t-1}$	Net Investment-Capital ratio	-0.60	1.20
$\Delta N_t/N_{t-1}$	Rel. Change of Employment	-0.50	1.00
$\log(G_t)$	R&D Capital		9.70
$\log(K_t)$	Physical Capital		10.8

* : trimming has been done on the basis of the nominal series.

Effects trimming :

Raw data set without missing values for G, K, N, Y : 1570 firms in the manufacturing sector; after trimming : 757 firms left; with 286 firms in the scientific sector in the 1959-1987 period; with 193 firms in the 1973-1987 period. After merging with the productivity database 104 firms in the 1959-1987 period were left with at least 9 consecutive observations.

Sample design scientific sector 1973-1987 : 193 firms, 1533 observations

Year	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
# Firms	42	46	83	126	133	131	127	124	120	111	110	103	98	96	83

SIC	28	283	357	36	38
# Obs	538	139	29	598	229

Characteristics of trimmed sample of
193 firms in scientific sector 1973-1987
(1533 observations unbalanced)

	mean	median	std. dev.	10%	90%
$\log G_t$	4.06	3.88	2.00	1.53	6.91
$\log K_t$	4.97	4.60	1.96	2.57	7.60
$\log N_t$ *	4.67	4.57	1.69	2.53	6.94
G_{-1}/Y_{-1}	0.177	0.167	0.106	0.0570	0.306
K_{-1}/Y_{-1}	0.411	0.346	0.237	0.191	0.705
N_{-1}/Y_{-1}	0.285	0.274	0.108	0.158	0.406
$\Delta G/G_{-1}$	0.116	0.106	0.0832	0.0342	0.206
$\Delta K/K_{-1}$	0.107	0.0923	0.167	-0.0704	0.304
$\Delta N/N_{-1}$	0.0924	0.0842	0.152	-0.0620	0.230

* : the labor series has been rescaled such that the median equals the median of the labor compensation series in Hall (1990a).

Variance Decomposition of Factor Demand
193 Scientfic Sector Firms 1973-1987
(1533 observations unbalanced)

	Log G	Log K	Log N
Total	3.99	3.84	2.83
Within 2 digit sic industry	3.59	3.37	2.67
Within 4 digit sic industry	1.82	1.60	1.41
Within firm	0.167	0.159	0.117

	$\Delta G/G_{-1}$	$\Delta K/K_{-1}$	$\Delta N/N_{-1}$
Total	0.0069	0.0278	0.0231
Within 2 digit sic industry	0.0067	0.0277	0.0230
Within 4 digit sic industry	0.0043	0.0259	0.0219
Within firm	0.0031	0.0254	0.0216

* : the labor series has been rescaled such that the median equals the median of the labor compensation series in Hall (1990a).

Appendix 2.C: List of Instruments for R&D equation *

$\Delta(Y_t/G_t)$

$\Delta(G_t p^G_{t-1} p^G_{t-1}/Y_{t-1})$	$\Delta(K_t p^G_{t-1} p^K_{t-1}/Y_{t-1})$	$\Delta(N_t p^G_{t-1} p^N_{t-1}/Y_{t-1})$
$\Delta(Y_{t-1} G_{t+1}/G_t G_{t-1})$	$\Delta(Y_{t-1} K_{t+1}/K_t G_{t-1})$	$\Delta(Y_{t-1} N_{t+1}/N_t G_{t-1})$
$\Delta(Y_{t-1} G_t/G_{t-1} G_{t-1})$	$\Delta(Y_{t-1} K_t/K_{t-1} G_{t-1})$	$\Delta(Y_{t-1} N_t/N_{t-1} G_{t-1})$
$\Delta(G_{t-2}/G_{t-3})$	$\Delta(K_{t-2}/K_{t-3})$	$\Delta(N_{t-2}/N_{t-3})$

$p^G_{t+1}, p^G_t, p^G_{t-1}, p^G_{t-2}$

and time dummies

* : all instruments (except prices and dummies) should be lagged θ_G+1 periods in the case of the R&D equation when the technology shocks are correlated. Mutatis mutandis for the instruments used for the other Euler equations. These instruments however are in levels, that is the Δ operation is not applied.

Appendix 2.D:

Restrictions used in ALS between the parameters in the Euler equation for R&D and the structural parameters

Regressor	Restriction
Y_0/G_0	$\zeta_1 = \dfrac{-\theta_{G1}}{(b_{GG}-d_{GG})}$
Y_0G_{-1}/G_0G_0	$\zeta_2 = \dfrac{(1-\gamma)\, d_{GG} + \gamma \dot{a}_{GG}}{\gamma\,(b_{GG}-d_{GG})}$ with $\dot{a}_{GG} = \vartheta_{G1}(1-\vartheta_{G1})$
Y_0K_{-1}/G_0K_0	$\zeta_3 = \dfrac{(1-\gamma)\, d_{KG} + \gamma \dot{a}_{GK}}{\gamma\,(b_{GG}-d_{GG})}$ with $\dot{a}_{GK} = -\,\vartheta_{G1}\vartheta_{K1}$
Y_0N_{-1}/G_0N_0	$\zeta_4 = \dfrac{(1-\gamma)\, d_{NG} + \gamma \dot{a}_{GN}}{\gamma\,(b_{GG}-d_{GG})}$ with $\dot{a}_{GN} = -\,\vartheta_{G1}\vartheta_{N1}$
$Y_0(G-G_{-1})/G_0G_0$	$\zeta_5 = \dfrac{b_{GG} - \gamma d_{GG} + \gamma \dot{a}_{GG}}{\gamma\,(b_{GG}-d_{GG})}$
$Y_0(K_{+1}-K)/G_0K_0$	$\zeta_6 = -\dfrac{(b_{GK}-d_{GK})}{(b_{GG}-d_{GG})}$
$Y_0(K-K_{-1})/G_0K_0$	$\zeta_7 = \dfrac{b_{GK} - \gamma d_{KG} + \gamma \dot{a}_{GK}}{\gamma\,(b_{GG}-d_{GG})}$
$Y_0(N_{+1}-N)/G_0N_0$	$\zeta_8 = -\dfrac{(b_{GN}-d_{GN})}{(b_{GG}-d_{GG})}$
$Y_0(N-N_{-1})/G_0N_0$	$\zeta_9 = \dfrac{b_{GN} - \gamma d_{NG} + \gamma \dot{a}_{GN}}{\gamma\,(b_{GG}-d_{GG})}$

Similar restrictions can be derived between the parameters of the other two Euler equations and the structural parameters.

Chapter 3

The Solution of the Linear Rational Expectations Model with Gestation Lags

3.1 Introduction

The realism and explanatory power of competitive equilibrium business cycle models have been enhanced by the introduction of the assumption of time-to-build in investment by Kydland and Prescott (1982). By its rigidity, this feature is capable of explaining the dynamics of factor demand and productivity above and beyond the part accounted for by adjustment cost specifications alone. Ioannides and Taub (1992) investigated the dynamic behavior of a deterministic continuous-time version of the Kydland and Prescott time-to-build model. In this chapter we analyse an extension of the discrete-time model of Kollintzas (1985) that allows for gestation lags.

In the eighties a number of articles have appeared that discuss the formulation, solution and estimation of models that belong to the class of Linear Rational Expectations (LRE) models. In an important contribution to this literature, Kollintzas (1985) proposes a solution method for multivariate LRE models that satisfy a symmetry condition. The Rational Multivariate Flexible Accelerator model is a well known example that fits in this framework. The solution method is based on the simultaneous diagonalization of the matrices of the lag polynomial of the Euler-Lagrange condition (ELC) and the application of the generalized Wiener-Kolmogorov prediction formulae. Fulfilment of the stability condition that is derived in that paper, is necessary and sufficient for the existence and uniqueness of the solution. In the same year Epstein and Yatchew (1985) introduced a simplified estimation procedure for some of these models. This procedure was extended to cope with more general models by Madan and Prucha (1989). However all these models have in common that they are (systems of) second order difference equations.

In this chapter recent developments in the literature are exploited to solve the symmetric LRE with gestation lags. Generally this feature of the model leads to a matrix lag polynomial of a higher order. Following Broze,

Gouriéroux and Szafarz (1991), the ELC's are restated as a reduced form in terms of realizations and revision processes. A convenient decomposition of the matrix lag polynomial is given that is at the root of the derivation of restrictions on the revision processes which restore the equivalence of both representations of the first order conditions to the LRE. Its usefulness also stems from the fact that it includes the matrix lag polynomial of the LRE without time-to-build and thereby allows us to show that the stability condition given in Kollintzas (1985) is also sufficient for the existence and uniqueness of the solution of this more general model. That is after adding the restrictions on the revision processes, that are implied by demanding stability , to the other restrictions, all revision processes can be written as a function of the exogenous processes. After the formulae of the revision processes expressed as a function of the exogenous processes have been substituted in the reduced form, the "stability" restrictions on the revision processes warrant the existence of a factorization of the matrix lag polynomial of the exogenous part of this form that includes a factor with the nonstable roots, such that they can cancel out. A lemma provides a procedure to obtain the formulae of the matrices of the factorization. In this way we are able to derive a closed form solution (CFS) of the LRE. The CFS is amenable to the procedures of Prucha and Madan (1989).

The chapter is organized as follows: in the next section the model is stated and the first-order conditions, the so called Euler-Lagrange equations (ELC), are derived. The third section contains the main results. Section 4 concludes.

3.2 The Model

In this section the symmetric linear rational expctations model with gestation lags is described.

Consider a representative economic agent who maximizes the expected discounted stream of cashflows given technological constraints and information on the economic environment. As far as the entrepreneur is concerned, the economic environment consists of product and factor markets. He is a price taker in both markets. Following Kollintzas (1985) the technology is characterized by

$$g(x_t, \Delta x_{t+1}, \mu_t) = a'x_t + \mu_t' x_t - \tfrac{1}{2} x_t' E x_t - x_t' H \Delta x_{t+1} - \tfrac{1}{2} \Delta x_{t+1}' G \Delta x_{t+1} \qquad (2.1)$$

where $x_t = (x_t^1\ x_t^2\ \dots\ x_t^F)'$ is a (F × 1) vector comprising the F stocks of production factors x_t^f, f = 1,...,F. The x_t's are decided upon at equidistant, discrete points in time. The (F × F) constant matrices E, G and H are symmetric, E is positive (semi-)definite and G is positive definite (PDS);

furthermore $\begin{bmatrix} E & H \\ H & G \end{bmatrix}$ is positive (semi-) definite and G - H is nonsingular ;

a is a (F × 1) vector of constants, while μ_t is a stochastic vector of technology shocks. The entrepreneur chooses a contingency plan that maximizes

$$\lim_{T\to\infty} E_0 \sum_{t=0}^{T} \gamma^t \left[g(x_t, \Delta x_{t+1}, \mu_t) - \sum_{f=1}^{F} p_t^f I_t^f \right] \tag{2.2}$$

subject to an initial condition and transversality conditions. The I_t^f, f=1,...,F, are the gross changes of the stocks, e.g. gross investments, and p_t^f are the corresponding real factor prices, that is factor prices deflated by the product price. γ is the real discount factor. The expectations are formed rationally. This entails that the subjective laws of motion match their objective equal and all information available is used.

It takes time to build new productive goods. Usually for the building of a plant, around two years is needed. When the decisions on the size of the stocks are observed twice in that period, or even more frequently, the standard laws of motion used for capital stock are inappropriate. Kydland and Prescott (1982) suggested a model that pays attention to the building time aspect of investment.

Let $s_{j,t}^f$ be the total size of an investment project of type f, j periods from completion, j=0,...,θ_f, where θ_f is the gestation lag. Then the building process for inputs of type f can be formalized as

$$x_{t+1}^f = (1 - \delta^f)\, x_t^f + s_{0,t+1}^f \tag{2.3a}$$

$$s_{j,t+1}^f = s_{j+1,t}^f \qquad j = 0,\dots,\theta_f - 1 \tag{2.3b}$$

where δ^f is the depreciation rate of inputs of type f. Furthermore let ψ_j^f be the share of the resources spent on investment projects that are finished in j periods. Total investment of type f in period t equals

$$I_t^f = \sum_{j=0}^{\theta_f} \psi_j^f s_{jt}^f \quad \text{with} \quad \sum_{j=0}^{\theta_f} \psi_j^f = 1 \tag{2.3c}$$

From combining (2.3a) to (2.3c) it follows that

$$I_t^f = \sum_{j=0}^{\theta_f+1} \Psi_j^f x_{t+j-1}^f \tag{2.4}$$

where the Ψ_j^f's depend on the ψ_j^f's and δ^f . After substituting this expression for I_t^f in (2.2), f=1,...,F, the first order conditions (ELC) for the stocks can be derived

$$E_{t-\theta_f}\left\{[G_{f.}-H_{f.}]x_{t+1} - [E_{f.} + \frac{(1+\gamma)}{\gamma}G_{f.} - 2H_{f.}]x_t + \frac{1}{\gamma}[G_{f.}-H_{f.}]x_{t-1}\right\} \tag{2.5}$$
$$+ a_f + E_{t-\theta_f}\mu_{ft} - \sum_{j=0}^{\theta_f+1}\Psi_{fj}\gamma^{-j+1}E_{t-\theta_f}[p_{t-j+1}^f] = 0 \qquad f = 1,...,F$$

where $A_{f.}$ is generic notation for the f-th row of matrix A.
Because of the gestation lags, at time t final decisions are made concerning $x_{t+\theta_1}^1, x_{t+\theta_2}^2, ..., x_{t+\theta_F}^F$. When the factor of production is not quasi-fixed, e.g. materials, the last term is just minus the current price $-p_t^f$.

3.3 The Existence, Uniqueness and Closed Form Representation of the Solution.

Defining L as the lag operator we can write system (2.5) succinctly as

$$E_t L^{-J}\Pi(L)y_t + u_t = 0 \tag{3.1}$$

with $y_t = [x_{t+\theta_1}^1, x_{t+\theta_2}^2, ..., x_{t+\theta_F}^F]'$
$J = \theta_1 - \theta_F + 1$ and assuming $\theta_1 \geq \theta_2 \geq ... \geq \theta_F \geq 0$

$$u_t = \begin{bmatrix} a_1 + E_t\mu_{1t+\theta_1} - \gamma^{-\theta_1}\sum_{j=0}^{\theta_1+1}\Psi^1_{\theta_1-j+1}\gamma^j E_t[p^1_{t+j}] \\ a_2 + E_t\mu_{2t+\theta_2} - \gamma^{-\theta_2}\sum_{j=0}^{\theta_2+1}\Psi^2_{\theta_2-j+1}\gamma^j E_t[p^2_{t+j}] \\ \vdots \qquad\qquad \vdots \\ a_F + E_t\mu_{Ft+\theta_F} - \gamma^{-\theta_F}\sum_{j=0}^{\theta_F+1}\Psi^F_{\theta_F-j+1}\gamma^j E_t[p^F_{t+j}] \end{bmatrix} = d_t + U(L)w_t \tag{3.2}$$ [1]

---

[1] A more general ARIMA model for u_t can be handled as we will see at the end

where $U(L) = U_0 + U_1 L^1 + \dots + U_\tau L^\tau$, w_t is a white noise process and d_t is the deterministic part of u_t.

$$\Pi(\lambda) = \Sigma_{i=-J}^{J} A_i \lambda^{J-i} \tag{3.3}$$

In the definition of the A_i's we use the definitions

$$C = [c_{jk}],\quad D = [d_{jk}]\quad (F \times F) \text{ with}$$

$$c_{jk} \equiv e_{jk} + \frac{(1+\gamma)}{\gamma} g_{jk} - 2h_{jk}\ ,\ d_{jk} \equiv g_{jk} - h_{jk}\quad j,k = 1,2,\dots,F$$

$$A_i = [\,a_{i,jk}]\quad (F \times F),\quad -J \le i \le J \text{ have nonzero elements } ^2$$

$$a_{\theta_j - \theta_k + 1, jk} = d_{jk}\quad a_{\theta_j - \theta_k, jk} = -c_{jk}\qquad a_{\theta_j - \theta_k - 1, jk} = \frac{1}{\gamma} d_{jk}$$

Introducing the vectors of revision processes $\varepsilon_t^j = E_t(y_{t+j}) - E_{t-1}(y_{t+j})$ $j = 0,\dots,\theta_1$, which are martingale differences, we obtain by replacing the expectations in (3.1) with realizations and revisions and after shifting the system J periods back in time (see Appendix 3.A)

$$\Pi(L) y_t = \Sigma_{i=0}^{J-1} \Sigma_{j=i+1}^{J} A_j L^{J-j+i} \varepsilon_t^i - u_{t-J} \tag{3.4}$$

The effective (not multiplied by zero) revision processes in (3.4) are ε_1^0, $\varepsilon_2^0,\dots,\varepsilon_2^{\theta_1 - \theta_2},\dots,\varepsilon_F^0,\dots,\varepsilon_F^{\theta_1 - \theta_F}$ where the subscript now indicates a production factor. Thus we have $(\theta_1 + 1)F - \sum_{i=1}^{F} \theta_i$ revision processes [3]. They are subject to constraints as we will show in the sequel.

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of this section, but for the moment we restrict the discussion to the MA representation of order τ for the sake of clarity.

[2] Matrices with the same subscripts should be added up.

[3] Hereafter the subscript of the revision processes will refer to a production factor or indicate time.

The dimension of the set of solutions that satisfy (3.1) depends on the number of free revision processes. The number of effective (univariate) martingale differences in (3.4) equals $(\theta_1+1)F - \sum_{i=1}^{F} \theta_i$. After imposing the constraints in (3.9), there are only F free revision processes left as we will prove now.

Lemma 2

The restrictions in (3.10) reduce the number of free revision processes in (3.4) by $\theta_1 F - \sum_{i=1}^{F} \theta_i$ [6].

Proof

The proof of lemma 2 consists of three steps. First we will demonstrate that the restrictions of lemma 1 do not involve revision processes different from those mentioned just below (3.4). Next we show that $(1-\theta_F)F + \sum_{i=1}^{F} \theta_i$ restrictions are redundant. Finally we look at a system which includes the effective restrictions. To carry out the first step, we will concentrate on the restriction which corresponds to taking expectations with respect to Ω_{t-J+1} *and* Ω_{t-J} *and taking* differences afterwards, since this restriction contains the revision processes with the most distant horizons and we could expect new revision processes to show up here, if anywhere.

Consider without loss of generality the i-th row of $L^{-\theta_1}P(L)\xi_{t-J}$,

$$\xi_{i,t-1-\theta_i+\theta_F} = -\sum_{j=0}^{J-1}\sum_{h=1}^{J} A_{-h,i.} L^{1+\theta_i-\theta_F+h}\varepsilon^j_{t-j} - \sum_{j=0}^{J-1}\sum_{h=0}^{j} A_{h,i.} L^{1+\theta_i-\theta_F-h}\varepsilon^j_{t-j} \tag{3.11}$$

The most recent observation of the k-th production factor y_k that appears in (3.11) is $y_{k,t-\theta_k+\theta_F}$. To show this we consider the following two cases.

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equation with respect to Ω_{t-i} for $i=0,\ldots,\theta_1-\theta_F$ does not yield a single constraint.

[6] This is in fact predicted by property (37) in the paper by Broze, Gouriéroux and Szafarz. However we believe that our proof, as it is confined to the particular model above, is more revealing and complete than their proof.

If $\theta_k > \theta_i + 1$ the most recent observation of y_k in (3.11) is part of the first double sum and corresponds to the smallest value of h for which $A_{-h,ik} \neq 0$, that is to $h = \theta_k - \theta_i - 1$. Note that in this case $A_{h,ik} = 0$ for $h \in \mathbb{N}$. If $\theta_k \leq \theta_i + 1$ the most recent observation of y_k in (3.11) is part of the second double sum and corresponds to the highest value of h for which $A_{h,ik} \neq 0$, that is to $h = \theta_i - \theta_k + 1$. Thus the revision processes with the most distant horizons are $\varepsilon_k^{\theta_1 - \theta_k}$, $k = 1,\ldots,F$. But they are included in the set of those mentioned below (3.4). This observation completes the first step.

The redundancy is easily demonstrated. Again we look at the i-th row of $L^{-\theta_1}P(L)\,[\xi_{t-J} - u_{t-J}]$. Since $\xi_{t-J} - u_{t-J}$ contains information only until time t-J, taking expectations of the i-th row of $L^{-\theta_1}P(L)\,[\xi_{t-J} - u_{t-J}]$ with respect to $\Omega_{t-\theta_i+\theta_F-1}$ is equivalent to taking expectations of the i-th row with respect to $\Omega_{t-\theta_i+\theta_F-1+j}$ for each $j \in \mathbb{N}$. So at least $(1-\theta_F)F + \sum_{i=1}^{F} \theta_i$ restrictions are redundant. The remaining restrictions of (3.10) are included in the following system

$$\begin{bmatrix} A_0 & A_1 & A_2 & \ldots & A_{J-2} & A_{J-1} \\ A_{-1} & A_0 & A_1 & \ldots & A_{J-3} & A_{J-2} \\ A_{-2} & A_{-1} & A_0 & \ldots & A_{J-4} & A_{J-3} \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ A_{-J+2} & A_{-J+3} & A_{-J+4} & \cdots & A_0 & A_1 \end{bmatrix} \begin{bmatrix} \varepsilon_t^0 \\ \varepsilon_t^1 \\ \varepsilon_t^2 \\ \vdots \\ \varepsilon_t^{J-1} \end{bmatrix} + \begin{bmatrix} U_0 \\ U_1 \\ \vdots \\ U_\tau \\ 0 \\ \vdots \\ 0 \end{bmatrix} w_t = 0 \qquad (3.12)$$

which is obtained by taking expectations of the i-th row of $L^{-\theta_1}P(L)\,[\xi_{t-J} - u_{t-J}]$ with respect to $\Omega_{t-\theta_i+\theta_F-j}$ for $j = 1,\ldots,J$ and taking differences of the adjacent expressions, for $i = 1,\ldots,F$. Apart from the restrictions in (3.10),

system (3.12) also includes $-\theta_F F + \sum_{i=1}^{F} \theta_i$ incorrect equations, which however can be ignored [7]. They can easily be recognized by making use of the fact that the true restrictions only involve the revision processes listed below (3.4). The vector $[(\varepsilon_t^1)'...(\varepsilon_t^{H-1})']'$ in (3.12) also includes $-\theta_F F + \sum_{i=1}^{F} \theta_i$ other revision processes [8], which are redundant as they enter only the false 'restrictions'.

In order to prove that the remaining restrictions from (3.10) are effective, it will now be shown that generally the matrix at the LHS of (3.12) has maximum rank. The Laplace development of the determinant of the matrix that is obtained by leaving out the last F colums, includes the product of the diagonal entries of that matrix, which are the diagonal entries of all A_0 matrices. Only the diagonal entries of A_0 depend on the diagonal entries of E. Since the sum of their powers in other terms of the Laplace development is lower, the determinant differs from zero in general [9]. But if all rows in (3.12) are independent, then the $\theta_1 F - \sum_{i=1}^{F} \theta_i$ true restrictions are also

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[7] Since the number of additional restrictions in (3.12) equals the number of revision processes introduced in these restrictions, they do not constrain the revision processes mentioned below (3.4).

[8] To discern the restrictions in (3.10) from the equations added in (3.12) we look at the diagonal of the matrix at the LHS of (3.12) comprised of A_1 matrices. Note that all diagonal entries of A_1 are different from zero since B is positive definite. The fact that each of the $-\theta_F F + \sum_{i=1}^{F} \theta_i$ redundant revision processes is multiplied by such an entry, enables us to locate all the restrictions, which do not emanate from (3.10). By premultiplying (3.12) by a diagonal selection matrix we get the system of true restrictions. The diagonal of the selection matrix is obtained by carrying out the following substitutions in $[(\varepsilon_t^1)'...(\varepsilon_t^{J-1})']'$: the revision processes mentioned below (3.4) are replaced by 1 and the remaining revision processes are replaced by zero.

[9] One corollary to lemma 4 below would say that the set of values of the diagonal of E for which the determinant is zero has Lebesgue measure zero.

independent. Finally, from the first step of the proof, where it was shown that no revision processes are included in (3.10) other than those mentioned below (3.4), it is immediately clear that taking expectations of (3.9) with respect to Ω_{t-J-j} with $j \in \mathbb{N}$ one does introduce new revision processes but also that the number of free revision processes remains constant: one can derive a new restriction for each new revision processes that is introduced. □

So all the revision processes in (3.4) but F are subject to restrictions. The space of candidate solutions to the optimal control problem that satisfy the Euler-Lagrange conditions will be reduced even further by imposing the tranversality condition or a stronger condition like stability . Generally such conditions guarantee uniqueness of the solution just as they do when there is no time-to-build. In the latter case $\Pi(\lambda) = Q(\lambda)$. Recall the decompositions in (3.5) and (3.6), then premultiplying both sides of equation (3.4) with $(S'\zeta)^{-1}L^{-\theta_1}P(L)$ leads to

$$(I + (\zeta^{-1})L + (I/\gamma)L^2)\ S\ L^{-\theta_F}P(L)y_t = \tag{3.13}$$
$$L^{-\theta_F}(S'\zeta)^{-1}\{ \textstyle\sum_{i=0}^{J-1}\sum_{j=i+1}^{J} P(L)A_j L^{1-j+i}\varepsilon_t^i - P(L)u_{t-1} \}$$

By virtue of (3.10), the number of revision processes in (3.13) can be reduced to F, say ε_t^0 [10]. Making the assumption that a solution y_t belongs to the class of ARIMA-processes we can parameterize ε_t^0 as Θw_t. Then the RHS of (3.13) is a distributed lag of w_t, $R(L)w_t = (R_0 + R_1L + ... + R_gL^g)w_t$ with $g = J+\tau$.

A solution of the stochastic optimal control problem must satisfy the transversality condition too. Sufficient conditions for this condition to hold are that the exogenous stochastic process w_t and a solution y_t are of exponential order less than $\gamma^{-1/2}$ (see Sargent (1987) pp. 200-201). The w_t process has this property by assumption. To ascertain this property in the case of y_t we investigate the LHS of (3.13). Let's define $\hat{Q}(\lambda) \equiv (I + (\zeta^{-1})\lambda + (I/\gamma)\lambda^2)$. Denote the roots of the f-th equation in $\hat{Q}(1/\lambda) = 0$ by λ_f^- and λ_f^+. All pairs of roots $\{\lambda_f^-, \lambda_f^+\}$ satisfy $\lambda_f^-\lambda_f^+ = \gamma^{-1}$. Let λ_f^- be the smaller

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[10] Generally the matrix that results from leaving out the first F columns from the matrix at the LHS of (3.12) is nonsingular.

modulus root of each pair. Then we have $|\lambda_f^-| \leq \gamma^{-1/2}$ and $|\lambda_f^+| \geq \gamma^{-1/2}$. The stability condition given in Kollintzas (1985) is necessary and sufficient for $|\lambda_f^-| < \gamma^{-1/2}$ to hold. For instance this condition is satisfied when the adjustment costs are strongly separable (H=0). Notice that if $|\lambda_f^-| < \gamma^{-1/2}$ then $\lambda_f^-, \lambda_f^+ \in \mathbb{R}$. But in order that the solution y_t is of exponential order less then $\gamma^{-1/2}$ we also need that R(L) can be factorized as $(1-\Lambda^+L)\bar{R}(L)$, where $\Lambda^+ = \mathrm{diag}(\lambda_1^+,...,\lambda_F^+)$ and $\bar{R}(L)$ is a lag polynomial of order g-1, for otherwise we are not able to get rid of the part of the LHS of (3.13) that causes violation of the condition, i.e. the factor corresponding to the larger roots $(1-\Lambda^+L)$.

The lemma below provides a condition that is equivalent to the existence of the factorization but more easily verifiable.

Lemma 3

Let $N(\lambda)=N_0 + N_1\lambda + ... + N_w\lambda^w$ be a polynomial of order w. This polynomial can be factorized as $(I-\Gamma\lambda)\bar{N}(\lambda)$ if and only if

$$\sum_{i=0}^{w} \Gamma^{w-i} N_i = 0 \tag{3.14}$$

Proof

Suppose this factorization is possible. Then $N(\lambda) = N_0 + N_1\lambda + ... + N_w\lambda^w = (1-\Gamma\lambda)(\bar{N}_0 + \bar{N}_1\lambda_1 + ... + \bar{N}_{w-1}\lambda^{w-1}) = \bar{N}_0 + (\bar{N}_1-\Gamma\bar{N}_0)\lambda + (\bar{N}_2-\Gamma\bar{N}_1)\lambda^2 + ... + (-\Gamma\bar{N}_{w-1})\lambda^w$. Equating powers of λ gives

$$N_0 = \bar{N}_0 \qquad N_i = \bar{N}_i - \Gamma\bar{N}_{i-1} \quad i=1,...,w-1 \qquad N_w = -\Gamma\bar{N}_{w-1} \tag{3.15}$$

It follows that $\sum_{i=0}^{w} \Gamma^{w-i} N_i = (\Gamma^w - \Gamma^{w-1}\Gamma)\bar{N}_0 + (\Gamma^{w-1} - \Gamma^{w-2}\Gamma)\bar{N}_1 + ... + (\Gamma - I\Gamma)\bar{N}_{w-1} = 0$. But condition (3.14) is also sufficient. We propose a factorization and next verify its validity. Use the formulae for N_0 through N_{w-1} in (3.15) recursively to obtain $\bar{N}_1, \bar{N}_2, ..., \bar{N}_{w-1}$. Then $\bar{N}_{w-1} = \sum_{i=0}^{w-1} \Gamma^{w-1-i} N_i$. Multiplying both sides by $-\Gamma$ and using condition (3.14) yields $-\Gamma\bar{N}_{w-1} = N_w$ which is in agreement with the last equality in (3.15). □

Substituting R(L) for $N(\lambda)$ and Λ^+ for Γ gives the condition

$$\sum_{i=0}^{g} (\Lambda^+)^{g-i} R_i = 0 \tag{3.16}$$

The matrices $R_0,\ldots,R_g$ depend on $F \times F$ unknown entries of Θ. But (3.16) imposes $F \times F$ restrictions on the Θ_{ij}'s. In general these restrictions uniquely identify Θ. To see this consider the RHS of (3.13) apart from the last term

$$L^{-\theta_F}(S'\zeta)^{-1}\Sigma_{i=0}^{J-1}\Sigma_{j=i+1}^{J} P(L)A_j L^{1-j+i}\varepsilon_t^i \equiv (\hat{R}_0+\hat{R}_1 L+ \ldots +\hat{R}_{J-1}L^{J-1})\varepsilon_t \tag{3.17}$$

where $\varepsilon_t=(\varepsilon_t^0\ldots\varepsilon_t^{J-1})'$ and $\hat{R}_i \equiv (\gamma S'\zeta)^{-1}[K_{i1}\ldots K_{iJ}]$, i=0,...,J-1

the $\hat{R}_i$'s are $F \times (J \times F)$ matrices and the K_{ij}'s are $F \times F$ matrices with

$$K_{ij} = 0 \qquad j > i+1 \qquad K_{ij} = \sum_{k=1}^{\bar{f}(i)} \bar{A}_{J+j-i-1,k} \quad 1 \le j \le i+1$$ [11]

$$\bar{A}_{J,1}=\begin{bmatrix} 0 & \ldots & 0 & \gamma d_{1F} \\ 0 & \ldots & 0 & 0 \\ \vdots & & \vdots & \vdots \\ 0 & \ldots & 0 & 0 \end{bmatrix}, \quad \bar{A}_{J-1,1}=\begin{bmatrix} 0 & \ldots & 0 & -\bar{c}_{1F} \\ 0 & \ldots & 0 & 0 \\ \vdots & & \vdots & \vdots \\ 0 & \ldots & 0 & 0 \end{bmatrix}, \quad \bar{A}_{J-2,1}=\begin{bmatrix} 0 & \ldots & 0 & d_{1F} \\ 0 & \ldots & 0 & 0 \\ \vdots & & \vdots & \vdots \\ 0 & \ldots & 0 & 0 \end{bmatrix}$$

$$\bar{A}_{J-3,1}=0,\ldots,\bar{A}_{\theta_1-\theta_{F-1}+1,1}=\begin{bmatrix} 0 & \ldots & 0 & \gamma d_{1F-1} & 0 \\ 0 & \ldots & 0 & 0 & 0 \\ \vdots & & \vdots & \vdots & \vdots \\ 0 & \ldots & 0 & 0 & 0 \end{bmatrix}, \quad \bar{A}_{\theta_1-\theta_{F-1},1}=\begin{bmatrix} 0 & \ldots & 0 & -\bar{c}_{1F-1} & 0 \\ 0 & \ldots & 0 & 0 & 0 \\ \vdots & & \vdots & \vdots & \vdots \\ 0 & \ldots & 0 & 0 & 0 \end{bmatrix},\ldots,$$

$$\bar{A}_{1,1}=\begin{bmatrix} \gamma d_{11} & 0 & \ldots & 0 \\ 0 & 0 & \ldots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \ldots & 0 \end{bmatrix},$$

$$\bar{A}_{J,2}=\begin{bmatrix} 0 & \ldots & 0 & 0 \\ 0 & \ldots & 0 & \gamma d_{2F} \\ 0 & \ldots & 0 & 0 \\ \vdots & & \vdots & \vdots \\ 0 & \ldots & 0 & 0 \end{bmatrix}, \quad \bar{A}_{J-1,2}=\begin{bmatrix} 0 & \ldots & 0 & 0 \\ 0 & \ldots & 0 & -\bar{c}_{2F} \\ 0 & \ldots & 0 & 0 \\ \vdots & & \vdots & \vdots \\ 0 & \ldots & 0 & 0 \end{bmatrix},\ldots, \quad \bar{A}_{\theta_1-\theta_2+1,2}=\begin{bmatrix} 0 & 0 & 0 & \ldots & 0 \\ 0 & \gamma d_{22} & 0 & \ldots & 0 \\ 0 & 0 & 0 & \ldots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & \ldots & 0 \end{bmatrix},\ldots,$$

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[11] $\bar{A}_{ij}$ matrices with the same indices should be added.

Lemma 4 [13]

Let p: $\mathbb{R}^n \to \mathbb{R}$ be a polynomial in n variables and let $p \not\equiv 0$.
Then $M(p) \equiv \left\{ x \in \mathbb{R}^n \mid p(x) = 0 \right\}$ has Lebesgue measure zero defined on $\mathbb{R}^n$.

Proof of lemma 4: by induction over the degree of p, see Appendix 3.C.

The determinant of a general matrix N is a polynomial, where the entries of the matrix are the variables. From lemma 4 it follows that the space of values of the entries of N for which det(N) = 0 has Lebesgue measure zero. The same lemma can be invoked when the entries are linear functions of (hyper-)parameters even if the number of parameters is smaller than the number of entries.

Because the entries of the last F rows of W are nonlinear functions of the entries of E,G, and H, theorem 1 has not been proved yet.

From (3.18) we know that the matrices B_i $i = 0,...,J-1$ depend in a nonlinear fashion on Λ^+, S, and ζ. These matrices in turn depend on $(C^{-1})D$ (see pages 5 and 10), where C and D are linear in (the entries of) E,G, and H, given γ (see page 4). Thus W depends on C and D. Define $X \equiv -(C^{-1})D$. The conditions on page 2 imply that $C \equiv E + G - 2H + (1/\gamma)G$ is PDS and $D \equiv G - H$ is nonsingular and therefore X is nonsingular. By fixing two matrices from the set {C, D, X} (without violating the conditions on page 2), for instance C and X, we fix the third and we fix W.

By fixing X we impose restrictions on C and D (E,G, and H) as $CX + D = 0$ must hold. Substitute these restrictions in (3.20) by replacing D by -CX. Then given X (and γ), W is linear in C. According to lemma 4 $M_{W,\gamma}$ has Lebesgue measure zero as long as det(W) is not trivially zero. This is indeed not the case for almost all choices of X, as will be shown below.

To this end we will develop the determinant of W. Some terms in the Laplace development consist of the product of the entries on the diagonal of the A_1-matrices and F entries of B_0. The sum of all these particular terms will be shown to be unique, that is its algebraic formula does not show up in another term of the Laplace development (LD) of the determinant of W, and therefore cannot cancel out. Furthermore this sum is different from zero in

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[13] Lemma 4 and its proof were suggested to us by A. Perea y Monsuwé.

general. This can easily be checked in the special case where $E = 0$, $G = \tilde{G}$, and $H = 0$. See appendix 3.D. From this simple example it follows that det(W) is not (always) the null function. Now let us return to the case of general X.

So given X, det(W) is not the null function unless a particular choice for X nullifies it to start with. Only for a very exceptional choice for X (a choice from a set of measure zero within the space of all possible choices for X) we might expect this to happen as will be shown now.

Notice again that when we fix X, C (or D) is still completely free; to be able to apply lemma 4 given a particular value of X, it suffices to show that $\det(W) \neq 0$ for one particular choice of the value of C (or D). As already indicated above, this will be done by looking for (algebraically) unique terms in the Laplace development of det(W). We will focus on the case where $C = \mathrm{diag}(c_{11},\ldots,c_{FF})$. Next we replace the c_{ii}'s by entries from X and D. Note that the entries from X and D have to satisfy the constraints $X + \mathrm{diag}(c_{11},\ldots,c_{FF})^{-1}D = 0$. Note further that X still can take any value by choosing D appropriately and when the diagonal entries of C are free but those of D are not, by choosing the c_{ii}'s and the nondiagonal entries of D appropriately.

In the remainder of the proof we will also exploit the fact that the d_{ii}'s only show up in the diagonals of A_{-1}, A_0, and of A_{+1}, and in B_0 but not in B_i, $i\neq 0$. As the latter is not obvious, we will prove that the d_{ff}, $f=1,\ldots,F$ show up in B_0 but not in B_i, $i\neq 0$, in appendix 3.E. Specifying only terms that do involve a d_{ii}, B_0 equals $\sum_{k=1}^{F} (\Lambda^+)^{g-\theta_k+\theta_F}(\gamma S'\zeta)^{-1}\bar{A}_{\theta_1-\theta_k+1,k} + \ldots$

Now we will show that there exists a unique part in the Laplace development of det(W), LD-part for short, which is the sum of all LD-terms that include the factor $\prod_{k=1}^{F} d_{kk}^{J-1}$ originating from the first (J-1)F rows of W, and the factor $\prod_{k=1}^{F} d_{kk}$ from the last F rows. This LD-part is meant to be unique in the sense that there are no other terms in the Laplace development of W that include the factor $\prod_{k=1}^{F} d_{kk}^{J}$. If such a unique LD-part exists and if the values of the d_{ii}'s can be chosen freely given X, then $\det(W)\neq 0$.

Note that because the first F(J-1) rows only have J-1 rows which involve a specific d_{ii}, $i=1,\ldots,F$, the highest power of d_{ii} that could be encountered in the part of an LD-term that originates from the first F(J-1) rows, is J-1. Furthermore the last F rows of W contribute F d_{ii}'s at most to a LD-term, which will all be different and originate form the first F columns (B_0).

Thus in order to obtain a LD-term that includes $\prod_{k=1}^{F} d_{kk}^{J}$ both parts of the W matrix — the upper F(J-1) rows and the lower F rows — must contribute the number of d_{ii}'s that can be attained at best (the values J-1 and 1 of the powers of d_{ii} in the upper part and lower part of W respectively are in fact upperbounds for the powers of d_{ii}, which however are attainable as will become clear). The rows in the upper part of W do not include different d_{ii}'s, while in B_0, d_{ii} shows up in the i-th column in every row (entry), for i=1,...,F.

The d_{ii}'s, that are contributed by the last F rows to the unique LD-part necessarily originate from the first F columns of W, that is from B_0. As a consequence the J-1 d_{ii}'s, for i=1,...,F, all have to come from W_M, which is a F(J-1) × F(J-1) matrix. This in turn uniquely determines the origin of the d_{ii}'s in the first F(J-1) rows as they all have to come from the diagonals of the A_1 matrices in W_M.

Given the unique origin of the d_{ii}'s in the LD-part, that come from the first F(J-1) rows, we are still left with many possible combinations of the entries in B_0 (which correspond to d_{ii}'s), as all possible combinations result in $\prod_{k=1}^{F} d_{kk}$. Because we can not pursue our search for a unique LD-term further at this point, we add up all LD-terms that involve $\prod_{k=1}^{F} d_{kk}^{J}$. The next step is to show that these terms almost always, that is for almost all X, do not counterbalance each other. As the factor in these LD-terms that comes from the first J(F-1) rows is always the same, namely $\gamma^{F(J-1)} \prod_{k=1}^{F} d_{kk}^{J-1}$, we focus on the distinguishing factors in the LD-terms which originate from B_0. Define the following matrix $Y = [y_{ij}]$, $y_{ij} = [(\gamma S'\zeta)^{-1}]_{ij} (\lambda_i^+)^{g-\theta_j+\theta_F}$. This matrix includes the "coefficients" of the d_{ii}'s in the LD-terms that originate from B_0. The sum of all coefficients of the $\prod_{k=1}^{F} d_{kk}$ factors in the LD-terms which originate from B_0, equals det(Y). Thus a necessary and sufficient condition for the existence of a unique LD-part that is characterized by $\prod_{k=1}^{F} d_{kk}^{J}$, i.e. a condition for this part of the LD not to equal zero, is that det(Y)≠0 (apart from the trivial condition that given X the d_{ii}'s do not equal zero). We will now show that det(Y)≠0 for almost all X. Notice that Y is a function of X and X alone.

For each matrix X we have a pair ζ, S^{-1}, the diagonal matrix with unique eigenvalues and a matrix of eigenvectors of X respectively, and vice versa. ζ_{kk} alone completely determines λ_k^+ for each k = 1,...,F. Since X can have all

values, ζ and S can have all values and vice versa. If we have chosen the values of the ζ_{kk}'s and thereby have fixed the λ_k^+'s, Y still can take on all values by choosing S appropriately. In fact given (almost all) ζ, there is an injective relation between Y and S. Thus given $\zeta=\zeta^*$, for almost all X with the eigenvalues equal to ζ_{kk}^*, k=1,...,F, or equivalently for almost all S, det(Y)≠0. For almost all values of ζ_{kk}^*, k=1,...,F, this argument applies. Furthermore by letting the ζ_{kk}^* take on all values in $\mathbb{R}$, k=1,...,F, and by choosing S given ζ^* appropriately, all X's are covered (can be generated). Thus for almost all X, the condition det(Y)≠0 is satisfied. As a consequence for almost all X there is a unique part in the Laplace development of W that depends on $\prod_{k=1}^{F} d_{kk}^J$. (Recall that it is unique because it is the only LD-part that involves $\prod_{k=1}^{F} d_{kk}^J$). Because the d_{ii}'s can be chosen freely, we can choose their values given X, in such a way that det(W)≠0. So for almost all X, det(W) is not trivially zero and by lemma 4, $M_{W,\gamma}$ has Lebesgue measure zero. Since the space of values of entries of X, for which det(W) is the null function, has Lebesque measure zero, $M_{W,\gamma}$ has Lebesgue measure zero unconditionally.

□

The uniqueness of the solution to the model warrants the existence of the closed form solution (CFS)

$$x_t = \Lambda x_{t-1} + \bar{R}(L)L^{\theta_F} w_t \qquad \text{with } \Lambda = S^{-1}\Lambda^- S, \quad \Lambda^- \equiv \mathrm{diag}(\lambda_1^-,\ldots,\lambda_F^-) \qquad (3.22)$$

Notice that the autoregressive part of the closed form solution is invariant with respect to the order of the gestation lags . Our strategy for deriving the formulae of the MA parameters in the CFS entails the following steps

1. Obtain expressions for ε_t ; from (3.21′) $\varepsilon_t = -\bar{W}^{-1}\bar{Z}w_t$
2. Substitute these expressions in the RHS of (3.13) and find formulae for R_0 up to R_g , $g = J + \tau$. Make use of (3.17).
3. Use the procedure in the proof of Lemma 3 to obtain the factorization $R(L) = (1-\Lambda^+L)\bar{R}(L)$, i.e. $\bar{R}_0, \bar{R}_1, \ldots, \bar{R}_{g-1}$

Let $M = I - \Lambda$. If $|M| \neq 0$, then (3.22) admits the flexible accelerator form

$$x_t - x_{t-1} = M\,(x_t^* - x_{t-1}) \quad \text{with} \quad x_t^* = M^{-1}\bar{R}(L)L^{\theta_F}w_t \tag{3.23}$$

This form is amenable to the estimation procedure first advanced by Epstein and Yatchew (1985) and extended by Madan and Prucha (1989). They also discuss an exhaustive set of properties of M that are implied by the structure of the problem. By demanding that the estimates of M exhibit these properties, more precise estimates can be obtained. Furthermore from (3.23) it is clear that even in the presence of gestation lags it is possible to impose the transversality condition on the equations to be estimated. However, since in non trivial problems the MA parameters in x_t^* depend in an intricate manner on the structural parameters due to the inversion of $\bar{W}$, these restrictions have to be ignored in those cases. Then we still have a semi closed form solution.

At the outset we assumed that $u_t \sim MA(\tau)$. However, it is well-known that prices follow more general ARIMA processes. In such cases the formula of the solution should be amended by using the following procedure. The autoregressive lag polynomial of the exogenous processes $\{u_t\}$ will be factorized, where one factor is a diagonal matrix lag polynomial with common roots on the diagonals : V(L). This factor includes for instance the unit roots from the prices. Then the ARI lag polynomial of the solution becomes $V(L)(1-\Lambda L)$. The second factor can be replaced by a $MA(\infty)$ representation. The stability condition can still be imposed. However the procedure to obtain expressions for the MA parameters in the CFS in terms of the structural parameters is no longer applicable. In practice the MA-part of the solution will be approximated with a stationary ARMA model.

In the model without adjustment costs, the autoregressive part of the solution equals the AR - part of the exogenous processes times the Hessian of the production function. From this observation it can be concluded that one does not need adjustment costs to explain autoregressive patterns in the factor demand relations. We do not need to impose stability to obtain a unique solution ; the restrictions in Lemma 1 are sufficient. However a necessary second order condition for the solution to be a maximum is that E is positive definite.

Finally the results that where derived above can also be obtained for nonsymmetric LRE models ($H \neq H'$) . A decomposition of the second order matrix

lag polynomial can be found in Cassing and Kollintzas (1991). Kollintzas (1986) gives a stability condition for such models.

3.4 Conclusions

In this chapter we have shown that the LRE model which allows for both adjustment cost considerations and gestation lags has a unique stable solution and moreover that it admits a closed form representation. The solution to the model differs from the solution to the model that only accounts for adjustment costs with respect to the moving average part. In this manner it reconciles more intricate dynamical patterns observed in the data. Although the restrictions between the MA parameters of the CFS and the structural parameters are often too complicated to be exploited, the restrictions on the AR parameters can be imposed. Indeed, estimating demand equations along with models for the price processes and the production function and imposing cross-equation restrictions will yield more efficient estimates of the parameters.

Appendix 3.A: Proof of equation (3.4)

(3.4) is the result of the following computations.

The system we are investigating is

$$E_t L^{-J} \Pi(L) y_t + u_t = 0 \tag{3.1}$$

substituting

$$\Pi(L) = \Sigma_{j=-J}^{J} A_j L^{J-j} \tag{3.3}$$

and lagging the system J periods gives

$$E_{t-J} \Sigma_{j=-J}^{J} A_j L^{J-j} y_t + u_{t-J} = 0 \Leftrightarrow$$

$$\Pi(L) y_t + \left\{ E_{t-J} \Sigma_{j=1}^{J} A_j L^{J-j} y_t \right\} - \Sigma_{j=1}^{J} A_j L^{J-j} y_t + u_{t-J} = 0 \Leftrightarrow$$

$$\Pi(L) y_t + \Sigma_{j=1}^{J} A_j \left\{ E_{t-J} y_{t-J+j} - y_{t-J+j} \right\} + u_{t-J} = 0$$

recalling that $\varepsilon_t^j = E_t y_{t+j} - E_{t-1} y_{t+j}$, we obtain

$$\Pi(L) y_t + \Sigma_{j=1}^{J} A_j \left\{ -\Sigma_{i=0}^{j-1} \varepsilon_{t-J+j-i}^{i} \right\} + u_{t-J} = 0$$

changing the order of summation yields

$$\Pi(L) y_t = \Sigma_{i=0}^{J-1} \Sigma_{j=i+1}^{J} A_j L^{J-j+i} \varepsilon_t^i - u_{t-J} \tag{3.4}$$

Appendix 3.B: Proof of equation (3.7)

Starting with the result shown in appendix 1, we have

$$\Pi(L)y_t = \Sigma_{j=0}^{J-1}\Sigma_{h=j+1}^{J} A_h L^{J-h+j}\varepsilon_t^j - u_{t-J} \Leftrightarrow \tag{3.4}$$

$$\Pi(L)y_t = \Pi(L)\left\{\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j\right\} - u_{t-J}$$
$$- \Sigma_{h=-J}^{J} A_h L^{J-h}\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j + \Sigma_{j=0}^{J-1}\Sigma_{h=j+1}^{J} A_h L^{J-h+j}\varepsilon_t^j \Leftrightarrow$$

$$\Pi(L)y_t = \Pi(L)\left\{\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j\right\} - u_{t-J}$$
$$- \Sigma_{j=0}^{J-1}\Sigma_{h=-J}^{J} A_h L^{J-h}\varepsilon_{t-j}^j + \Sigma_{j=0}^{J-1}\Sigma_{h=j+1}^{J} A_h L^{J-h+j}\varepsilon_t^j \Leftrightarrow$$

$$\Pi(L)y_t = \Pi(L)\left\{\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j\right\} - u_{t-J} - \Sigma_{j=0}^{J-1}\Sigma_{h=1}^{J} A_{-h} L^{J+h+j}\varepsilon_t^j$$

$$- \Sigma_{j=0}^{J-1}\Sigma_{h=0}^{J} A_h L^{J-h+j}\varepsilon_t^j + \Sigma_{j=0}^{J-1}\Sigma_{j=j+1}^{J} A_h L^{J-h+j}\varepsilon_t^j \Leftrightarrow$$

$$\Pi(L)y_t = \Pi(L)\left\{\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j\right\} - u_{t-J} - \Sigma_{j=0}^{J-1}\Sigma_{h=1}^{J} A_{-h} L^{J+h+j}\varepsilon_t^j$$
$$- \Sigma_{j=0}^{J-1}\Sigma_{h=0}^{j} A_h L^{J-h+j}\varepsilon_t^j$$

which can be written as

$$\Pi(L)y_t = \Pi(L)\left\{\Sigma_{j=0}^{J-1}\varepsilon_{t-j}^j\right\} + \xi_{t-J} - u_{t-J} \tag{3.7}$$

where $\xi_{t-J} = -\sum_{j=0}^{J-1}\sum_{h=1}^{J} A_{-h} L^{J+h+j}\varepsilon_t^j - \sum_{j=0}^{J-1}\sum_{h=0}^{j} A_h L^{J-h+j}\varepsilon_t^j$

Appendix 3.C: Proof of Lemma 4 [14]

Induction over degree of p.

Let the degree of p equal 0. Then p is a constant. As $p \not\equiv 0$, p has no roots. Thus $M(p) = \emptyset$, and has Lebesgue measure zero.
Induction step: Let the degree of p equal $r \geq 1$ and let the lemma be true for p with degree $\leq r-1$.

Since the degree of p is at least 1, there is an $i \in \{1,\ldots,n\}$ with $\frac{\partial p}{\partial x_i} \not\equiv 0$. Assume w.l.o.g. that $\frac{\partial p}{\partial x_n} \not\equiv 0$.

Define the function $f(x) := \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ p(x_1,\ldots,x_n) \end{bmatrix}$

Because $p(x)=0$ for all $x \in M(p)$, it follows that $f(M(p)) \subseteq \mathbb{R}^{n-1} \times \{0\}$.
If f is a differentiable function, which is locally invertible almost everywhere, i.e. invertible for all $x \in \mathbb{R}^n \backslash M_0$ where M_0 is a set that has measure zero, then f is a local diffeomorphism almost everywhere. As will be shown below, we can cover $M(p)\backslash M_0$ by a countable union of open sets on each of which f is a (global) diffeomorphism. The image of the intersection of each of these open sets with $M(p)\backslash M_0$ under f is a subset of $\mathbb{R}^{n-1} \times \{0\}$, which has measure zero in $\mathbb{R}^n$. If f is a diffeomorphism on $\mathbb{R}^n \backslash M_0$, it follows that the intersection of each open set with $M(p)\backslash M_0$ has Lebesgue measure zero. Since $M(p)\backslash M_0$ is a countable union of sets with Lebesgue measure zero, $M(p)\backslash M_0$ has measure zero. From the fact that M_0 has measure zero, it follows that M(p) has measure zero.
Thus it remains to show that f is differentiable and locally invertible and that $M(p) \subseteq \bigcup_{i \in I} B_i$, where the B_i's are open sets on which f is a global diffeomorphism and I is a countable set.
It is easy to verify that f is differentiable. Next we focus on the property of local invertibility.

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[14] This proof was suggested to us by A. Perea y Monsuwé.

The derivative of f, $D_x f$ is:

$$D_x f = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & 0 \cdots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 \; 1 & 0 \\ * & * & \cdots * & \frac{\partial p}{\partial x_n} \end{bmatrix}$$

Thus $\det(D_x f) = \frac{\partial p}{\partial x_n}$. This is a function of $x_1,\ldots,x_n$. We know that $\frac{\partial p}{\partial x_n}$ is a polynomial in $\mathbb{R}^n$ of degree $\leq$ r-1. From the induction assumption, it follows that $M_0 = \{ x \mid \frac{\partial p}{\partial x_n} = 0 \}$ has measure zero. Thus $\det(D_x f) \neq 0 \; \forall \; x \in \mathbb{R}^n \backslash M_0$. Applying the implicit function theorem, it follows that f is locally invertible on $\mathbb{R}^n \backslash M_0$, where M_0 has Lebesgue measure zero.To show that we can cover M(p) by a countable union of open sets on which f is a global diffeomorphism, we will first proof that M(p) is a closed set.

M(p) is a closed set iff every convergent sequence $x^k \in M(p)$ converges to a limit in M(p). Now let x^k be a sequence in M(p) coverging to x. Thus $f(x^k) = 0$ $\forall$ k. From the fact that f is continuous, it follows that $f(x) = 0$.

We can always cover M(p) by the union of open sets on each of which f is a diffeomorphism. We will show that we can find a countable number of such sets. Define $M^k \equiv M(p) \cap C^k$ where $C^k = \{ x \in \mathbb{R}^n \mid \|x\|_\infty \leq k \}$.

Since C^k is compact and M(p) is closed, M^k is compact.

Thus we can find a cover $(B_i)_{i \in I_k}$ for M^k , where I_k has a finite number of elements. It follows that $M(p) = \bigcup_k M^k \subseteq \bigcup_k \bigcup_{i \in I_k} B_i = \bigcup_{i \in \hat{I}} B_i$, where $\hat{I} = \bigcup_k I_k$ is a countable set. □

Appendix 3.D: Det(W) when E = 0, G = $\tilde{G}$, and H = 0.

In this case $C = \frac{1+\gamma}{\gamma}\tilde{G}$ and $D = \tilde{G}$. It follows that $B_0 = -\frac{1+\gamma}{\gamma}\,\mathrm{diag}(\tilde{g}_{11},\ldots,\tilde{g}_{FF})$ and $B_i = 0$ for i = 1,...,J-1. Partition W as

$$W = \begin{bmatrix} W_1 & \vdots & W_m \\ B_0 & \vdots & W_2 \end{bmatrix}$$

By the theorem on the partitioned inverse, (the absolute value of) the determinant of W equals

$$|W| = |W_m|\,|B_0 - W_2 W_m^{-1} W_1|$$

Since $B_i = 0$ for i = 1,...,J-1 we have $W_2 = 0$. Thus $|B_0 - W_2 W_m^{-1} W_1| = |B_0| = \prod_{i=1}^{F} B_{0,ii} \neq 0$ because $D = \tilde{G}$ is nonsingular. It is easily seen from the definitions that the product of the diagonal entries of W_m is a unique term in the Laplace development of $\det(W_m)$. Thus in general $\det(W_m) \neq 0$ as well. It follows that $|W| \neq 0$ for almost all choices of $\tilde{G}$ when E = 0, G = $\tilde{G}$, and H = 0.

Appendix 3.E: d_{ff}, f=1,...,F, show up in B_0 but not in B_i , i≠0.

The proof proceeds as follows:
The d_{ff}'s (could only) enter the formulae of the B_i's through $K_{j\,i+1}$ j=i,...,J-1, i=0,...,J-1, which are sums of $\bar{A}_{kl}$ matrices. Now γd_{ff} only appears as the (f,f)-entry of $\bar{A}_{\theta_1-\theta_f+1,i}$,f=1,...,F . We will show that these matrices are only part of B_0 . Abstracting from factors that only depend on X, the B_i matrices equal $\sum_{j=i}^{J-1} K_{j\,i+1} = \sum_{j=i}^{J-1}\sum_{k=1}^{\tilde{f}(j)} \bar{A}_{J+i-j,k}$.
Suppose that $\bar{A}_{\theta_1-\theta_f+1,i}$ enters B_i , then $J+i-j=J+\theta_F-\theta_f$, k=f. It follows that $i=\theta_F-\theta_f+j$ and $\tilde{f}(j)\geq f$. From the latter we have $j\leq\theta_f-\theta_F$, and therefore i≤0. Thus d_{ff} , f=1,...,F, only show up in B_0 . □

Chapter 4

Consequences of Capital Market Imperfections For the Adjustment of the Stocks of Physical and Knowledge Capital

4.1 Introduction

In recent years there is revived academic interest in the linkages between the firm's financial structure and its 'real-side' behavior. Tax considerations and the presence of asymmetric information between owners/management and outside investors or agency costs lead firms to prefer internal capital over external capital. Starting with the article by Fazzari, Hubbard and Petersen (1988), several empirical papers addressed the question whether investments were hampered by liquidity constraints and in particular which firms were most likely to face them. A growing literature stresses that changes in the ability of the firm to acquire external funds (agency costs) — due, for instance, to changing cash flows or prospects concerning future profits — affect the production and factor demand decisions and thereby amplify and propagate business cycle fluctuations. Bernanke, Gertler and Gilchrist (1993) presented several pieces of evidence, that taken, together show that at the onset of a recession small firms that are bank dependent will receive a lower share of credit extended, that is, there is a flight to quality. As a consequence, some investment plans of such borrowers will be postponed till better times.

In this chapter, the role of agency costs in the investment process of firms is investigated once more. We study to what extent (differences in) the speed of adjusting the stocks of physical and knowledge capital and the level of investment and R&D expenditures are related to the height of the agency costs. We follow both a structural "Euler equation" approach and a less structural "partial adjustment" approach. While others have used only firm size as proxy for agency costs, e.g. Gilchrist (1990), or only financial variables like leverage as Whited (1992) did, we will use both kinds of determinants.

The models will be estimated using data pertaining to firms in the U.S. scientific sector in the period 1978-1987. As these firms are among those with the highest R&D intensity and therefore are likely to face relatively high agency costs ceteris paribus, this sample is particularly suited for testing theories that predict an effect of agency costs on investment behavior.

We find some evidence that smaller firms respond quicker to changing market conditions as far as investment in plant and equipment is concerned. This finding is consistent with a theory that says that firms that experience relatively high opportunity costs of capital, e.g. small or highly leveraged firms, will have less excess capacity in general. Although quicker adjustment of quasi-fixed inputs is more expensive in itself, firms do not have to borrow as much as they otherwise would have.

However, the interpretation of a relation between size and speed of adjustment is subject to ambiguity. It might well be the case that smaller firms are just more flexible and thus face lower adjustment costs. To discriminate between alternative explanations of the effect of size on the adjustment process special attention is paid to asymmetries in behavior at different stages of the business cycle.

During the eighties the United States witnessed a dramatic rise of corporate leverage. Many policymakers started to worry about the real effects of this increase. If it is true that highly leveraged firms operate differently because high cost of additional external capital render them dependent on the cash flow they generate internally, this development has implications for the shape of business cycles.

Highly leveraged firms that have invested considerably in R&D form a class of firms that are especially sensitive to shocks. These firms have a smaller so-called debt capacity since part of their assets are highly specific and cannot be used as collateral. Opler and Titman (1993) present evidence that during downturns sales drop dramatically in highly leveraged, R&D intensive industries. Furthermore, as predicted by Shleifer and Vishny (1992), stock returns decrease more, which also suggests that financial distress is more costly for these firms.

In contrast to the results for plant and equipment (P&E), no noticeable impact on the adjustment speed of R&D is found from factors that influence the agency costs. Moreover, the results indicate that the negative (partial) correlation between the level of R&D spending and leverage across firms, that was found by Long and Malitz (1985) and Hall (1991, 1992), disappears once

asymmetrical effects are accounted for.

Finally, the results obtained for the Euler equations of both knowledge and physical capital support the existence of asymmetries in adjustment behavior over the business cycle.

The outline of the chapter is as follows. In the next section, we discuss recent developments in the financial position of firms in more detail and summarize related papers. In section 3, we present the framework of our tests and discuss methodological issues. Section 4 presents the empirical results and section 5 concludes.

4.2 Agency Costs: recent Developments and Consequences

The impact of an adverse economic shock on the economy depends partly on the vulnerability of firms. In addition to institutional, organizational and technological factors, which determine how fast a firm can adjust to a changing environment, the values of liquidity measures and of financial ratios as leverage are important. In this study, we focus on the effect of agency costs on the investment behavior of firms. Various aspects of the way firms react to changing financial conditions have been the subject of previous studies, which we will briefly review in this section.

The likelihood of financial distress has changed considerably over time. After a period of steady decrease since the mid seventies, the leverage of firms started to rise again in 1985 [1]. However the peak that was reached in 1974 is still far away. The recent increase in leverage is partly a consequence of the major corporate restructuring that took place.

A number of recent theoretical and empirical papers have analyzed the consequences of high leverage for real economic behavior of the firm. The leveraged buyouts and acquisitions only had a small effect on spending on R&D since they were concentrated in industries with low R&D intensities. There also were a lot of companies that increased their leverage considerably without change of owners. Among them were many firms from the so-called scientific sector. Hall (1990b) found significant declines in investment in R&D as a result of this type of restructuring.

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[1] See Bernanke and Campbell (1988) and Bernanke, Campbell and Whited (1990).

The literature offers several explanations for the negative correlation between leverage and R&D intensity. Some theories explain why the cost of external finance may be higher for R&D than for ordinary investment, which leads managers to prefer internal funds as means of finance for R&D.

First R&D can hardly be used as collateral, since R&D is often a highly firm specific investment. Second, firms have an incentive not to reveal any information on R&D projects, which is valuable for competitors. This makes it harder to assess their value and the risk involved. According to Leland and Pyle (1977) asymmetric information problems can be severe in the case of risky investments such as R&D projects. The lemons premium that a firm has to pay when issuing new bonds or shares to finance an investment project can be so high that the manager, who acts in the interest of existing shareholders, forgoes the investment opportunity. This type of reasoning lead Myers and Majluf (1984) to conclude that there is a financial hierarchy, in which retained earnings are the cheapest source of funds. Third Jensen and Meckling (1976) argue that when a firm is highly leveraged and performing badly, it is tempting for managers who maximize the wealth of shareholders, to pursue a gambling strategy by borrowing more money and investing the money in risky projects, e.g. R&D. If they are successful bankruptcy may have been averted, if not the costs are borne by the lender. As lenders are aware of this moral hazard problem, they charge a higher interest rate and as a consequence the costs that arise from this problem are ultimately born by the borrowers. On the other hand, Myers (1977) pointed out that shareholders are not prepared to invest additional funds in a new project when a firm is in financial distress, as it is unlikely that they, as residual claimants, get a fair share of the profits.

For these reasons, the costs of external finance is relatively high for R&D intensive firms, that is when they are not subject to rationing. In addition, the interest, which has to be paid on debt, reduces the amount of internal finance which is available for R&D expenditure. Tables 6 to 8 in Bernanke and Campbell (1988) show that the burden of interest payments has increased considerably in the eighties. The ratio of interest expense to cash flow rose sharply, particularly in the upper tail of the distribution [2].

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[2] Obviously financial distress is a phenomenon that mostly happens to firms at the high percentiles of the distributions of leverage and liquidity measures. The interest expense as a ratio to a three-year moving average of the cash

Many papers have focused on the impact of agency costs on the demand for other inputs than R&D. In Whited (1992) the failure of the standard Euler equation to pass the Sargan test is found to be related to a binding debt constraint. An extended model, that is obtained by parameterizing the corresponding shadow price in the spirit of MaCurdy (1981) as a function of factors that measure the likelihood of financial distress, is more capable of explaining the data.

Sharpe (1994) examines the relationship between leverage and size and the speed of adjustment of the labor force to new economic conditions in three different ways. The empirical results indicate that employment growth is more sensitive to demand and financial conditions at more highly leveraged and/or smaller firms. Related evidence is provided by Cantor (1990). He reports a greater average volatility of the employment growth rates of more highly leveraged firms. Even after controlling for a variety of other firm characteristics he finds a higher (partial) correlation between (the volatility of) employment growth and (the volatility of) cash flows for more highly leveraged firms. Similar results are documented for capital expenditures. He interprets his findings as support for the view that highly leveraged firms have to respond more quickly and more sharply to worsening economic conditions by adjusting their factor demand in order to avoid default as they have relatively large debt service obligations and often face credit constraints at times they need extra funds most.

The so-called financial accelerator theory of the business cycle — which was formally introduced by Bernanke and Gertler (1989) but is reminiscent of the debt deflation theory of Fisher (1933)— offers a well-wrought explanation for the results of Sharpe and Cantor as well. The agency cost of financing depends on the quality of the firms balance sheet among other things. Since the firms net worth is likely to be procyclical, agency costs are lower in a business upturn and therefore investment is expected to increase. Gertler (1990) develops a multi-period framework that allows borrowers and lenders to have on-going relationships. As a consequence the agency costs of external funds become dependent also on the present value of forecasted future cash flows, as it can serve as collateral. Then small persistent changes in the value of important macroeconomic variables can cause large fluctutations in

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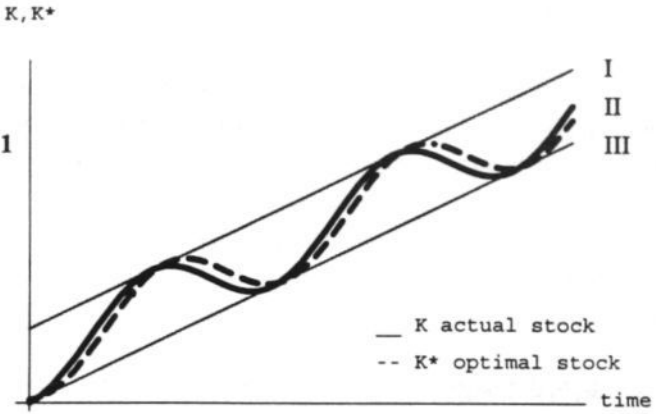
flow of COMPUSTAT firms rose from 0.44 in 1971 to 1.48 in 1986 at the 90th percentile.

the value of this part of the collateral and thereby induce large fluctuations in production through the financial accelerator mechanism.

Several articles have tested the implications of the Bernanke-Gertler framework. At the beginning of a recession or following a tightening of monetary policy, there is a clear shift in the composition of external finance. Kashyap, Stein and Wilcox (1993) present evidence that indicates that following a tightening of monetary policy the issuance of commercial paper increases, while bank loans fall. Although more firms would like to borrow in an economic downturn as on average their cash flows fall and their financing requirements increase (in particular the need to finance inventory stocks), only large firms with reasonable looking balance sheets can resort to issuance of commercial paper. Investment is affected by a shift in the loan supply, even after controlling for output and interest rates. This shift also explains why Kashyap, Lamont and Stein (1993) find that firms that are bank dependent (typically small firms) had to dispose of inventories more often than non bank dependent firms. Gertler and Gilchrist (1993) show that the situation for the former categrory is even worse : when we restrict our attention to bank loans, the credit extended to small firms after a tightening of monetary policy falls relative to credit extended to large firms. Bernanke and Lown (1993) attribute the slow recovery of the American economy after the 1990-1991 recession to the low quality of borrowers, which is due to high debt and interest coverage and resulted in a restrained lending policy of banks. Remelona et al. (1993) show that in recent years firms have started to deleverage to reduce the debt overhang problem.

The potential differences between the time-series behavior of P&E of a low leverage firm and of a high leverage firm can be illustrated using figure 1. The dotted line represents the development of the optimal capital stock and displays the pattern of a business cycle. When the real "user" cost of capital are low and the net adjustment costs function has a large positive second derivative, it is sensible to adjust the stock of capital at a constant pace and to maintain overcapacity to accommodate peaks in demand (line 1) ceteris paribus. If the user costs of capital rises due to a higher leverage, excess capacity will decline and adjustments will take place in a more flexible manner (line 2). When both changes of marginal adjustments and the use of capital are very expensive, capacity is just enough to satisfy demand during recessions (line 3). The investments of firms with these characteristics are hardly accelerated to take advantage of extra demand during peaks.

Figure 1



As mentioned above there are several theories that can explain the negative correlation between leverage and the average level of R&D we observe in a cross-section of firms. However it is an open question whether spending on R&D, like ordinary investments, could be expected to be more volatile for highly leveraged firms. There are good reasons why this is not necessarily true. It should be noted that although both types of capital are inherently quasi-fixed they differ crucially in a number of respects. First R&D projects are often longlasting and it often takes years before they lead to an innovation. Second R&D investments are to a large extent firm specific which explains why there is no second hand market. Actually only a direct competitor of the firm may be interested in buying blueprints or hiring its highly qualified engineers. Many R&D investments are literally embodied in the engineers and firing them in order to survive an economic downturn could lead to an immense loss of knowledge, which is not easy to recover after the recession. Third R&D efforts are not directly related to the current production of goods and services. Therefore a temporary decline in sales does not imply that the firm needs less R&D during that period although for instance some of its blue collar workers will be laid off. The R&D efforts are to a large extent aimed at enhancing future production / sales possibilities and decreasing unit costs. That is, R&D is a strategic factor, that is also used to protect market shares by deterring entrants.

In this chapter we investigate the consequences of capital market imperfections for the (speed of) adjustment of capital and R&D in particular to the target stocks in more depth.

4.3 Methodology

In this section we introduce two models that can serve as a workhorse for testing the hypothesis that the speed of adjustment of P&E and R&D is higher for firms that face higher agency costs of borrowing. The inference will start on the basis of a simple partial adjustment (cost) model for each type of capital. In order to avoid extreme heteroskedasticity — due to size differences between firms — the model has been formulated in terms of logarithms.

$$\ln X_{it} = -\mu_1 \lambda_{it} t + \mu_0 \lambda_{it} \ln S_{it} + (1-\lambda_{it}) \ln X_{it-1} + f_i + u_{it} \qquad (3.1)$$

where w_{it} is an innovation, f_i is the fixed effect, X_i is capital of firm i of whatever kind and S is sales. The parameter μ_1 is a productivity trend and $1/\mu_0$ is a scale parameter. λ_{it} denotes the speed of adjustment of capital and can vary over time and across firms. A firm is said to adjust the stock of capital quickly when λ_{it} is close to 1. For the purpose of testing a natural way to proceed is to write λ_{it} as a function [3] of factors that influence the agency costs and to substitute that expression for λ_{it} in equation (3.1). To keep things simple let the adjustment speed function read as

$$\lambda_{it} = \lambda_0 + \lambda_1 \text{LEVerage}_{it} + \lambda_2 \text{SIZE}_{it} \; (+ \lambda_3 \text{R\&D int}_{it}) \; ^4 \qquad (3.2)$$

Note that this adjustment speed function is not restricted to lie between 0 and 1. We will also consider a logistic specification for λ_{it} that guarantees that these restrictions are satisfied. However attention is primarily focused on the signs of the coefficients of leverage and size. According to our hypothesis λ_{it} should be a positive function of leverage and R&D intensity and a negative function of size.

The second model that we will consider consists of the Euler equations corresponding to the value maximization problem of a firm with possibly non-constant returns to scale and interactive adjustment costs. Furthermore we allow for the possibility that the firm operates in an output market that is

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[3] Coen (1971) modified the standard partial adjustment model for investment in a similar way by allowing the adjustment speed to depend on cash flow.

[4] R&D intensity is included as a source of agency costs that affects the speed of adjustment in the case of physical capital.

characterized by monopolistic competition. The first order condition will reflect the fact that knowledge is accumulated according to another rule than the linear schedule that is often assumed for physical capital.

We will now develop the model in its mathematical details. Abstracting from issuance of new equity and omitting the subscript i of the firm, the entrepreneur is assumed to maximize the present value

$$E_t(PV_t) = E_t\left\{ \sum_{s=0}^{\infty} \gamma_{t,s}(CF_{t+s} + \Delta B_{t+s} - (1-\tau)r_{t+s}B_{t+s-1})\right\} \tag{3.3}$$

where $\gamma_{t,s} \equiv \prod_{j=0}^{s} (1+\rho_{t+j})^{-1}$ is the discount factor between period t and s and ρ_{t+s} is the after tax required rate of return in period t+j, CF_t is the cash flow gross of interest payments, B_t is debt, τ is the corporate tax rate and r_t is the market rate of interest in period t.

Maximization is subject to constraints on the accumulation of the quasi-fixed factors, i.e. physical capital K_t and knowledge capital G_t. The restriction for the stock of productive physical capital is standard :

$$K_t = (1-\delta^K)K_{t-1} + I_t \tag{3.4}$$

where I_t is gross investment in physical capital and δ^K is the depreciation rate. Note that the investments become productive immediately. For R&D we adopt the law of motion used by Hall and Hayashi (1989), using R_t for R&D expenditures

$$G_t = cG_{t-1}^{1-\nu}R_{t-1}^{\nu} \tag{3.5}$$

This model can be interpreted as a knowledge production function. The parameter ν represents technological opportunity. Unlike the linear accumulation schedule, this specification does not imply that more investment today leads to less investment next period ceteris paribus [5]; it is consistent with the empirical observation made by Hall, Griliches and Hausman (1986) that $\log(R_t)$ displays positive autocorrelation [6]. The constant c in (3.5) depends

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[5] Klette (1994) p. 7 shows that if the value function is not too concave in the factors of production, then the growth of R&D expenditures is positively related to the growth of the stock of knowledge capital.

[6] For $\log(R_t)$, which is a very persistent series, they find that an

on the parameter ν, a depreciation parameter of R&D δ^G and a growth parameter of R&D expenditures g (see Appendix 4.A).
Gross cash flow is defined by the following equation

$$CF_t = (1-\tau)(\tilde{p}_t(Y_t,\varepsilon_t^D)Y_t - \tilde{p}_t AC_t(N_t,\Delta N_t,K_t,I_t,G_t,R_t) - \tilde{p}_t^G R_t) - \tilde{p}_t^N N_t - \tilde{p}_t^K I_t - \tilde{p}_t^Z Z_t \tag{3.6}$$

where $\tilde{p}_t(Y_t,\varepsilon_t^D)$ denotes the inverse demand function that reads as

$$\tilde{p}_t = \tilde{p}_t(Y_t,\varepsilon_t^D) = \varepsilon_t^D Y_t^{-\psi^D} \tag{3.7}$$

where ε_t^D is a demand shock and ψ^D is the elasticity of demand with respect to the firms output Y.

Apart from quasi-fixed inputs the production function depends on variable inputs like energy, materials as well as the length of the workweek. They are comprised in the vector Z. N denotes labor. The stocks and flows of the inputs (and the output) are premultiplied by their prices. We assume that the firm has a Cobb-Douglas technology

$$Y_t = \alpha_{0,t} K_t^{\alpha_K} G_t^{\alpha_G} N_t^{\alpha_N} Z_t^{\alpha_Z} \tag{3.8}$$

Finally $AC_t(.)$ measures the adjustment costs and is parameterized as follows

$$AC_t(N_t,\Delta N_t,K_t,I_t,G_t,R_t) = \tag{3.9}$$

$$\tfrac{1}{2}\phi_K\left(\frac{I_t}{K_t} - c_K\right)I_t + \tfrac{1}{2}\phi_G\left(\frac{R_t}{G_t} - c_G\right)R_t + \phi_{GK}\frac{I_t R_t}{\sqrt{K_t G_t}}$$

Before we give the Euler equations let us introduce three more symbols: C_t is the variable costs of goods sold, S_t is sales and will be used as a proxy for output and $\eta \equiv \alpha_G + \alpha_K + \alpha_N + \alpha_Z$ is the degree of returns to scale. The first order conditions for a solution to the firm's objective (3.3), up to second order terms, are

R&D:

(3.10a)

$$E_t\left\{(1-\psi^D)(\nu/\theta)(\eta-\alpha_K-\alpha_N)\left\{\frac{S_t}{G_t}\left[\frac{R_{t-1}}{G_{t-1}}\right]^{\nu-1}\right\} - (\nu/\theta)\left\{\frac{C_t}{G_t}\left[\frac{R_{t-1}}{G_{t-1}}\right]^{\nu-1}\right\}\right.$$

$$- (1+\rho)\phi_G\left[\frac{R_{t-1}}{G_{t-1}}\right] + \phi_G(c(1-\nu) + \tfrac{1}{2}(\nu/\theta))\left[\frac{R_t}{G_t}\right]^2\left[\frac{R_{t-1}}{G_{t-1}}\right]^{\nu-1} + \tfrac{1}{2}(1+\rho)\phi_G c_G$$

$$- (1+\rho)\phi_{GK}\frac{I_{t-1}}{\sqrt{K_{t-1}G_{t-1}}} + \phi_{GK}(c(1-\nu) + \tfrac{1}{2}(\nu/\theta))\frac{I_t}{\sqrt{K_t G_t}}\left[\frac{R_t}{G_t}\right]\left[\frac{R_{t-1}}{G_{t-1}}\right]^{\nu-1}$$

$$\left. - (1+\rho)p^G_{t-1}/(1-\tau) + c(1-\nu)(p^G_t/(1-\tau) - \tfrac{1}{2}\phi_G c_G)\left[\frac{R_t}{G_t}\right]\left[\frac{R_{t-1}}{G_{t-1}}\right]^{\nu-1}\right\} = 0$$

with $\theta \equiv (1/c)^{1/\nu}$ $\quad c \equiv (1+g)\left[\frac{1}{\delta^G+g}\right]^{\nu}$

PHYSICAL CAPITAL:

(3.10b)

$$E_t\left\{(1-\psi^D)(\eta-\alpha_G-\alpha_N)\left[\frac{S_t}{G_t}\right] - \left[\frac{C_t}{G_t}\right] - \phi_K\left[\frac{I_t}{K_t}\right] + \frac{(1-\delta^K)}{(1+\rho)}\phi_K\left[\frac{I_{t+1}}{K_{t+1}}\right]\right.$$

$$+ \tfrac{1}{2}\phi_K\left[\frac{I_t}{K_t}\right]^2 - \phi_{GK}\frac{R_t}{\sqrt{K_t G_t}} + \frac{(1-\delta^K)}{(1+\rho)}\phi_{GK}\frac{R_{t+1}}{\sqrt{K_{t+1}G_{t+1}}} + \tfrac{1}{2}\phi_{GK}\frac{R_t}{\sqrt{K_t G_t}}\left[\frac{I_t}{K_t}\right]$$

$$\left. - p^K_t/(1-\tau) + \frac{(1-\delta^K)}{(1+\rho)}p^K_{t+1}/(1-\tau)\right\} = 0$$

DEBT:

(3.10c)

$$1 - (1 + (1-\tau)r_t)/(1+\rho_t) = 0$$

Assuming that the firm's decisions are based on rational expectations as far as future variables are concerned, the equations that will be estimated are obtained by substituting realizations plus prediction errors for these variables and by imposing a normalization rules. After fixing some parameters like depreciation rates and adding time dummies to take care of macroeconomic phenomena and after differencing to remove heterogeneity in the mean, the model can be estimated by applying the Generalized Method of Moments [7] [8].

To test the central hypothesis of this paper we let the adjustment parameters of the first model depend on factors that are believed to influence the height of the agency costs. With respect to the second model we will follow a different procedure. The sample is split in two subsamples according to leverage [9]. If the firm's medium leverage is below a certain percentile in the industry it belongs to, its observations are assigned to the low-leverage subsample [10], if not they are assigned to the other subsample. Next the model is estimated on the basis of the whole sample while allowing the adjustment parameters to differ across subsamples. For that matter it is practical to define a dummy that is one if an observation is from the high-leverage subsample and to add the adjustment variables multiplied by that dummy. Then evaluating the financial accelerator hypothesis boils down to testing null-restrictions.

It cannot be ruled out a priori that the coefficient of C_t (cost of goods sold) varies across subsamples. Some game theoretic models on market behavior purport that oligopolistic firms with high leverage ratios can sustain tacit collusion only at relatively low markups on prices, e.g. Stenbacka (1992).

So far firms are assumed to respond symmetrically to improving and deteriorating market conditions. For several reasons it is doubtful that this is true. First descriptive statistics and results using econometric models, e.g. Neftçi (1984) reveal that business cycles are asymmetric. The duration of

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[7] The choice of the values of the parameters that will be fixed will be discussed hereafter along with the estimation results.

[8] The regression equations that have been estimated can be found in Appendix 4.B.

[9] Gilchrist (1990) estimates an Euler equation for physical capital on the basis of subsamples that correspond to different categories of firmsize.

[10] Leverage is defined as the ratio of the book value of debt over the book value of total assets both net of short term assets.

a contraction is shorter than the duration of a spell of prosperity. Nevertheless recessions often start with sharp declines of the production volume [11]. Although one could argue that firing is the mirrorimage of hiring, this does not hold analogously for capital of whatever kind. Many investment projects are irreversible or, put differently, the outlay for such projects should be considered as sunk cost. Unlike the workforce, the capital stock is owned by the firm. Selling part of it, for instance because the firm faces overcapacity during a recession, does not look like a wise policy in many instances. The prices on the second hand market are likely to be low as redundancy of capital will be widespread in the economy. Therefore net investment is bounded from below by depreciation.

The existence of agency costs or more generally liquidity constraints might add to asymmetries in the adjustment process over the business cycle. The threat of bankruptcy may force a highly leveraged firm to respond more quickly to a worsening of economic conditions. Sharpe (1994) finds a significantly negative effect of firm size on the adjustment speed of labor during a recession but no effect during an expansion.

To allow for the possibility of asymmetry in speed of adjustment between downturns and upturns, model (3.1) will be extended. The parameters of the terms that have been added are deviations from the values that adjustment parameters take on in good times. The structural models are modified for the same reason by adding all regressors multiplied by a recession dummy [12]. To investigate whether differences in adjustment behavior between firms are mainly due to the combination of contraction and high leverage, the Euler equations will be estimated again on the basis of redefined subsamples, where the second subsample contains the observations of highly leveraged firms during the recession years only.

It could be argued that a positive correlation between leverage and speed of adjustment is due to the fact that a firm can only finance quick expansion by issuing a lot of debt. By using lagged values of leverage and size, this interpretation of the results is no longer possible.

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[11] See the volume on business cycles edited by Gordon (1986).

[12] Chevalier and Scharfstein (1994) present evidence that supermarkets that are liquidity constrained during recessions boost their nominal sales by raising the markups.

Another endogeneity issue arises because of the technological relationship between output and inputs. To elicit the effect of a change in sales due to changes in demand, equation (3.1) is estimated with instrumental variables. The set of instruments includes, apart from lagged firm variables, series that are informative about the phase of the business cycle like volume of industrial production in the manufacturing sector, CPI, rate of capacity utilization and the official discount rate of the Federal Reserve Bank of New York.

The data that are used in this study for inference are recorded at the end of the fiscal year of firms. For a better analyis of phenomena due to the recession, we take advantage of the fact that the fiscal year-ends of firms fall into different months. The observations of the business cycle variables, which are available at a semiannual frequency, are matched to the firm data.

4.4 Empirical Results

The models (3.1) and (3.11) have been estimated with firm data from the Manufacturing Sector Masterfile (MSMF) which was created by Hall (1990a) and relies on information collected by Compustat. In this study, we focus on firms with their main activities in one of the following industries: chemicals (pharmaceuticals excluded) (SIC 28), pharmaceuticals, cosmetics (soap) and medical instruments (SIC 283, 284, 384), computing and office machines, radio, television and communication equipment (SIC 357, 365-367) and electric machines, electronics and scientific instruments (SIC 36,38). These industries constitute the so-called scientific sector and have high R&D intensities. Most of these industries (except perhaps part of SIC 28) produce durable goods and are likely to display more cyclical behavior than the nondurables sector. Therefore the phenomena we are interested in are expected to reveal themselves more clearly in the sample we have chosen. On the other hand as the shares of all firms in the dataset are traded at the stock exchange, asymmetric information problems will not add much to other market imperfections.

For cleaning of the dataset, we refer to chapter 2. Firms that went through major restructurings, like mergers, were dropped from the dataset. Because the panel was left unbalanced, biases due to attrition were not exacerbated.

Producer price information was obtained at the 4 digit SIC level from the productivity database (Gray and Bartelsman, 1994). Their tables also contained

prices of fixed capital at the 3 digit level. For the construction of the relative price of capital goods, the (replacement) value of the capital stock and the measurement and sources of some other series we refer to Whited (1992).

The R&D stock in the dataset has been constructed according to the rule $G_t = (1-\delta^G)\, G_{t-1} + R_t$ rather than to the version with a delivery lag of one period (A.3), which underlies the derivation of the formula for the accumulation constant c. Therefore G_t in the structural model will be measured by the lagged series (G_{t-1}) from the dataset. The R&D intensity is measured as the ratio of the R&D stock to sales. This measure is more stable than the one that is based on expenditures and therefore more likely to tell us something about the long run R&D policy of the firm.

The sample period is 1978-1987. Waves preceding 1978 were used for the calculation of instruments. The sample period includes the recession(s) in the early eighties. They cover the period 1980-1982 almost entirely, except for a few months in 1981. The recession of 1980 was preceded by a period of tight money. Therefore observations of the fiscal years ending in 1980-1982 are assigned to the recession subsample. The subsample of highly leveraged firms has been constructed by comparing the firm's medium leverage to the medium leverage of other firms in the industry it belongs to. Thirty percent of the firms with the highest leverage are assigned to one subsample, the remainder of the sample constitutes the other subsample.

Table 1 and figure 2 describe the cross-sectional distribution of the main variables as well as the development of some series that are related to agency costs over time. Note that also in our sample the interest coverage rate increased considerably in the mid 1980s. Furthermore after the recession of 1982 the medium leverage did not decrease, although the value of the average firm rose sharply. The dramatic changes in the capital structures took place in the second half of the 1980s, while our sample ends in 1987. However as long as the financial-real interactions we are studying here are stable across business cycles, the results obtained are informative with regard to what happened after 1987.

The series of the sources of agency costs, viz, firm size, leverage, interest coverage ratio and R&D intensity have been normalized so that the average value for each characteristic in the relevant (sub-)sample is zero. Thus λ_0 is the adjustment speed of the "average" firm in every respect.

Table I
Summary Statistics
(cross-sectional distribution)

Variables	Mean	Median	90%	Std. Dev.
Firm's median [1]				
I/K	0.167	0.145	0.285	0.077
R/G	0.220	0.185	0.325	0.222
$\Delta S/S_{-1}$	0.115	0.100	0.247	0.134
S/K	3.31	3.17	5.20	1.45
G/S	0.175	0.163	0.301	0.0953
LEV[2]	0.106	0.0882	0.238	0.102
INTIR[3]	0.480	0.362	0.946	0.359
SIZE[4]	4.19	3.78	7.34	2.10
Firm's std. dev. [5]				
StDev(I/K)	0.0518	0.0436	0.105	0.0331
StDev(R/G)	0.0473	0.0236	0.100	0.0802
StDev($\Delta S/S_{-1}$)	0.131	0.116	0.231	0.0973

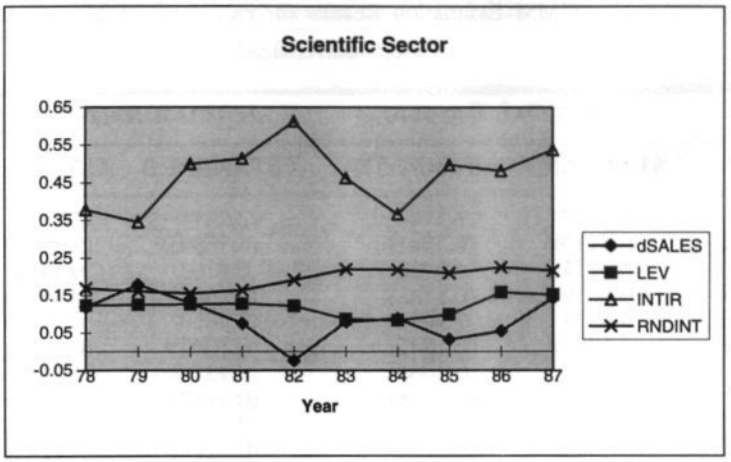
[1] The underlying sample has 1014 observations. the medians have been computed for 211 firms.

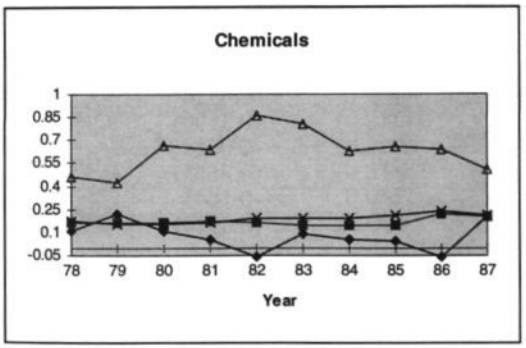
[2] LEV is the net leverage ratio, i.e. the book value of total debt over assets, both net of short-term assets.

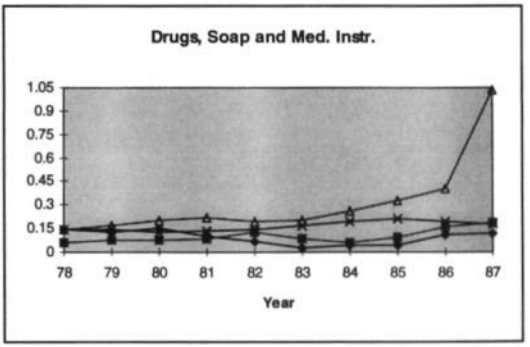
[3] INTIR is the interest coverage ratio, that is interest expense divided by income available for common.

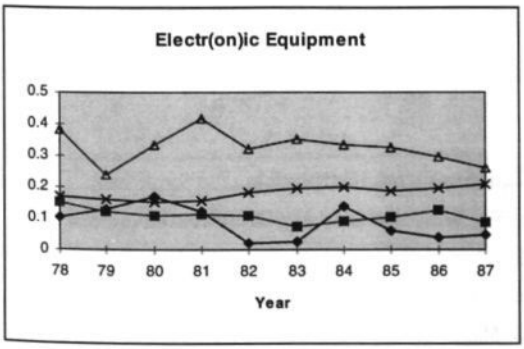
[4] SIZE is logarithm of net value of plant adjusted for for inflation.

[5] Std. dev. is standard deviation, which could be computed for only 178 firms.


Scientific Sector
0.65
0.55
0.45
0.35
0.25
0.15
0.05
-0.05
78 79 80 81 82 83 84 85 86 87
Year
dSALES
LEV
INTIR
RNDINT


Chemicals
1
0.85
0.7
0.55
0.4
0.25
0.1
-0.05
78 79 80 81 82 83 84 85 86 87
Year


Drugs, Soap and Med. Instr.
1.05
0.9
0.75
0.6
0.45
0.3
0.15
0
78 79 80 81 82 83 84 85 86 87
Year


Electr(on)ic Equipment
0.5
0.4
0.3
0.2
0.1
0
78 79 80 81 82 83 84 85 86 87
Year

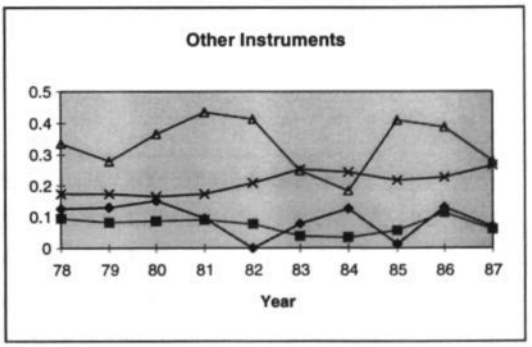

Other Instruments
0.5
0.4
0.3
0.2
0.1
0
78 79 80 81 82 83 84 85 86 87
Year

Table IIa

GMM Estimation Results for model (3.1,3.2) *

Twice Differenced

	PHYSICAL CAPITAL		R & D	
	STANDARD	ASYMMETRY	STANDARD	ASYMMETRY
β_2	1.0407	1.3747	-2.2378	-2.3173
	(0.5110)	(0.5961)	(1.7658)	(2.3047)
β_3	-0.0574	0.0722	0.1163	0.1484
	(0.0239)	(0.1102)	(0.0698)	(0.0721)
β_4	0.9365	0.9682	0.7869	0.8700
	(0.1567)	(0.1840)	(0.1202)	(0.1145)
β_5	0.0842	0.1660	-0.1376	0.0725
	(0.2156)	(0.2358)	(0.1137)	(0.1455)
β_6	0.1938	0.1472	0.1731	0.1583
	(0.2486)	(0.2837)	(0.1146)	(0.1222)
β_7	-0.4087	-0.2579	-0.1093	-0.0244
	(0.1505)	(0.1862)	(0.0569)	(0.0654)
$A\beta_2$		-2.0265		3.6252
		(2.2485)		(3.4730)
$A\beta_3$		-0.0501		-0.2433
		(0.1799)		(0.1121)
$A\beta_4$		0.5345		-0.4514
		(0.2904)		(0.3590)
$A\beta_6$		0.1079		-0.0524
		(0.6665)		(0.2655)
$A\beta_7$		-0.3784		-0.1645
		(0.4114)		(0.0974)
SARGAN	23.51	15.42	23.72	15.79
(D.F.)	(23)	(18)	(23)	(18)
β_5=1 D.T.	33.33	8.67	84.61	36.91
(D.F.)	(1)	(1)	(1)	(1)
ASYM DISTANCE TEST (D.F.)		8.09		7.93
		(5)		(5)

* See Appendix 4.B for Regression Equations and Instruments.

Obs. 1014, # Firms 211 Period 1978-1987, Time and Industry Dummies have been added, HAC Standard Errors below Estimates, Distance Tests (D.T.) for $\beta_5 = 1$ and Joint Significance of Asymmetry Regressors. $A\beta_i$ are deviations from values of parameters during expansion stage of the business cycle.

Table IIb

GMM Estimation Results model (3.1,3.2) *

First Differences

	PHYSICAL CAPITAL		R & D	
	STANDARD	ASYMMETRY	STANDARD	ASYMMETRY
β_2	-1.1288	-1.9502	-0.2155	-0.0043
	(0.5466)	(0.8798)	(0.2170)	(0.2987)
β_3	-0.0724	-0.0701	-0.0163	-0.0020
	(0.0293)	(0.0379)	(0.0191)	(0.0287)
β_4	0.6091	0.5939	0.1733	0.0579
	(0.0894)	(0.1015)	(0.0617)	(0.0794)
β_5	0.7134	0.7644	-0.0512	0.4985
	(0.1476)	(0.1608)	(0.6277)	(0.3762)
β_6	-0.1591	-0.2048	-0.0710	0.0071
	(0.1137)	(0.1312)	(0.0526)	(0.0636)
β_7	-0.0048	-0.0025	-0.0049	-0.0012
	(0.0050)	(0.0057)	(0.0045)	(0.0041)
$A\beta_2$		2.8998		0.1656
		(1.4828)		(0.5378)
$A\beta_3$		0.0303		-0.0129
		(0.0823)		(0.0478)
$A\beta_4$		0.1091		0.2622
		(0.2157)		(0.1088)
$A\beta_6$		0.3902		0.0448
		(0.3156)		(0.1370)
$A\beta_7$		0.0011		-0.0014
		(0.0124)		(0.0074)
SARGAN	17.52	12.42	35.26	22.93
(D.F.)	(23)	(18)	(23)	(18)
β_5=1 D.T.	4.62	2.58	6.36	3.01
(D.F.)	(1)	(1)	(1)	(1)
ASYM DISTANCE		5.10		12.33
TEST (D.F.)		(5)		(5)
$*\beta_2=*\beta_3=0$	12.66	16.54	2.63	0.38
D.T.(D.F.)	(2)	(4)	(2)	(4)
$*\beta_2=0$	4.87	7.22	1.06	0.16
D.T.(D.F.)	(1)	(2)	(1)	(2)

* See Appendix 4.B for Regression Equations and Instruments.

Obs. 1014, # Firms 211 Period 1978-1987, Time and Industry Dummies have been added, HAC Standard Errors below Estimates, Distance Tests (D.T.) for Joint Significance of Asymmetry Regressors, β_5 = 1 et cetera . $A\beta_i$ are deviations from values of parameters during expansion stage of the business cycle.

The set of instruments used for estimating (3.1) consists of the second lags of leverage and size and R&D intensity, their products with $\Delta S_{t-2}/S_{t-3}$, I_{t-2}/K_{t-3} or R_{t-2}/G_{t-3} and second and third lags of I_t/K_{t-1} or R_t/G_{t-1}, $\Delta S_t/S_{t-1}$ and the business cycle indicators. When estimating the structural equations only lagged series of the regressors and the dependent variable were used as instruments. Both the regressors and the instruments were multiplied by the regime dummies when testing for the constancy of parameters [13].

4.4.1 Estimation Results for the Partial Adjustment Model

Tables 2A and 2B show GMM estimates for two versions of the partial adjustment model (3.1). The first column is based on the original model, while the second column corresponds to the model that allows for asymmetry between expansions and contractions. Since leverage or size might affect the level of investment directly, the restrictions from the adjustment speed function (3.2) were not imposed on the coefficients of the sources of agency costs when they enter separately. The results presented are obtained after first differencing the original equation in (3.1) twice (table 2A) and only once (table 2B) to deal with heterogeneity in the mean and depreciation rates. Furthermore the nominal series were not deflated and capital is measured by the NPLANT series from MSMF.

Before we discuss the coefficients of size and leverage, we note that the elasticity of scale parameter, which would equal 1 under constant returns to scale (CRS), is poorly estimated in table 2A. On the other hand the adjustment speed of the average firm is highly significant but rather high again when the estimates are obtained after taking first differences twice. Since both CRS cannot be rejected and the implied adjustment speeds look more reasonble for the once differenced version, we prefer the results in table 2B. The results indicate that only ordinary investment depends on leverage. In table 2A the adjustment speed of physical capital is higher for highly leveraged firms as predicted by the theory. The relation between leverage and the adjustment speed is constant across different phases of the business cycle. When looking at table 2B, we find that leverage has a negative effect on the adjustment speed, but if we allow for asymmetry the sign of the effect is reversed during

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[13] The complete lists of instruments can be found in Appendix 4.B below the regression equations.

a recession. The size of the firm has an impact on both ordinary and R&D investment in a direct way and through the adjustment speed. The sign of the effect is predominantly negative, with the exception of the adjustment speed of R&D during the expansion (table 2A).

Now focusing on table 2B only, we conclude from the values of the test statistics and the implied t-ratios that R&D is not affected by leverage and size. There is evidence for asymmetry in the adjustment speed of R&D but this is not related to size or leverage effects, which casts doubt on the financial accelerator theory. The (symmetric) size effect that was found for physical capital can be perfectly explained by the idea that smaller firms are just more flexible.

The linear specification for the adjustment speed function may be problematic when the implied speed is negative or higher than one for some observations. To check the robustness of the results discussed above, we reestimated the models in first differences, with a logistic specification for the adjustment speed (3.2′) [14]. We also considered more parsimonious specifications than the general symmetric and asymmetric models reported on in table 2B. The most informative results are shown in table 2C for R&D and in table 2D for physical capital. Looking at table 2C, we find that in the symmetric case the scale parameter β_5 is (still) close to zero, in fact even negative, and very imprecisely estimated. The preferred, asymmetric, model is shown in the last column, which confirms our conclusions based on table 2B: there is a difference in the speed of adjustment across stages of the business cycle, but that is not related to agency costs considerations. Interestingly, the size effects and the direct leverage effect in the symmetric model — indeed in agreement with what one might expect [15] — are no longer significant once asymmetry is allowed for. The story told by table 2B about physical capital is supported by the results in table 2D [16]: smaller firms are more flexible, and there is no evidence of asymmetrical effects.

The absense of an effect of leverage on R&D spending could be due to the

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[14] This specification can be found in appendix 4.B.

[15] One might entertain the hypotheses that smaller firms are more flexible and invest more because they are still growing, and that leverage has a depressing effect on investment.

[16] The iterations of the estimation procedure for the most general asymmetric specification did not converge due to numerical problems.

Table IIc

GMM Estimation Results model (3.1,3.2′) *

First Differences – Logistic Adj. Speed Function

	R & D			
	STANDARD	STANDARD	ASYMMETRY	ASYMMETRY
β_2	-3.1264 (2.1495)	-3.4074 (1.5975)	-2.1740 (5.3518)	
β_3	-0.3647 (0.1456)	-0.3713 (0.1557)	-0.0200 (0.7350)	
β_4	-2.2412 (0.5166)	-2.1755 (0.5287)	-2.4013 (0.8874)	-2.6942 (0.8033)
β_5	-0.0920 (0.5477)	0.0000 ( )	0.6120 (0.7786)	0.5532 (0.3056)
β_6	-0.0745 (0.0446)	-0.0748 (0.0410)	-0.0174 (0.0532)	
β_7	-0.0077 (0.0022)	-0.0078 (0.0016)	-0.0010 (0.0061)	
$A\beta_2$			4.3072 (7.7964)	
$A\beta_3$			-0.0327 (0.6238)	
$A\beta_4$			1.7519 (1.3803)	2.0174 (0.8507)
$A\beta_6$			0.1182 (0.1944)	
$A\beta_7$			-0.0012 (0.0025)	
SARGAN-1 (D.F.)	27.49 (23)	27.83 (24)	20.95 (18)	23.95 (26)
SARGAN-2 (D.F.)			22.40 (18)	24.30 (26)
$\beta_5=1$ D.T. (D.F.)	11.07 (1)	12.68 (1)	1.89 (1)	3.37 (1)
ASYM DISTANCE TEST (D.F.)			11.36 (5)	
$*\beta_2=*\beta_6=0$ D.T.(D.F.)	2.69 (2)	8.05 (2)	0.91 (4)	
$L\beta_2=L\beta_3=L\beta_6=L\beta_7=0$ D.T.(D.F.)			0.89 (4)	

* See Appendix 4.B for Regression Equations and Instruments. Program: TSP # Obs. 1014, # Firms 211 Period 1978-1987. See also notes to table IIb. Sargan-1 is based on optimal weighting matrix, Sargan-2 on other weighting matrix which is held constant across different models tested in ASYM. columns.

Table IId

GMM Estimation Results model (3.1,3.2′) *

First Differences – Logistic Adj. Speed Function

	PHYSICAL CAPITAL			
	STANDARD	ASYMMETRY	ASYMMETRY	ASYMMETRY
β_2	-4.7444 (3.9548)		-6.5595 (5.6555)	
β_3	-0.3839 (0.1508)	-0.5263 (0.2354)	-0.5459 (0.2771)	-0.4049 (0.1663)
β_4	0.1251 (0.3711)	-0.4217 (0.5637)	0.1295 (0.5073)	-0.0134 (0.4371)
β_5	0.7779 (0.1379)	0.7886 (0.1467)	0.7864 (0.1330)	0.8007 (0.1365)
β_6	-0.0730 (0.0976)		-0.0717 (0.1076)	
β_7	-0.0050 (0.0043)	-0.0060 (0.0048)	-0.0060 (0.0051)	-0.0061 0.0047
$A\beta_2$				
$A\beta_3$		0.3216 (0.3413)		
$A\beta_4$		0.9502 (0.8604)	0.1813 (0.8131)	0.7041 (0.8584)
$A\beta_6$			-0.0643 (0.0833)	
$A\beta_7$		0.0039 (0.0095)	-0.0038 (0.0034)	
SARGAN-1 (D.F.)	14.99 (23)	14.31 (22)	13.34 (20)	14.75 (24)
SARGAN-2 (D.F.)		16.47 (22)		17.71 (24)
$\beta_5=1$ D.T. (D.F.)	2.83 (1)			2.27 (1)
ASYM DISTANCE TEST (D.F.)		1.43 (3)	1.63 (3)	0.20 (1)
$\beta_2=\beta_6=0$ D.T. (D.F.)	2.91 (2)	4.44 (2)		2.98 (2)
$L\beta_6=L\beta_7=0$ D.T. (D.F.)			1.37 (2)	
$L\beta_2=L\beta_3 \mid L\beta_6=L\beta_7=0$ D.T. (D.F.)			2.65 (2)	

* See Appendix 4.B for Regression Equations and Instruments. Program: TSP # Obs. 1014, # Firms 211 Period 1978-1987. See also notes to table IIc.

fact that leverage and debt capacity of a firm are likely to be positvely correlated. In that case, omitting the latter would result in underestimating the effect of leverage. However we will control for debt capacity to some extent in the structural approach by splitting the sample on the basis of thresholds for debt that are defined at the industrial level.

On the other hand it could well be true that leverage does not affect R&D spending. As we argued above R&D doesn't contribute directly to production but is a long term activity which takes place at a rather constant rate as changes are costly. The marginal effectiveness of R&D will fluctuate less over the business cycle than that of labor given the production capacity of the firm. Therefore highly leveraged firms that face the threat of financial distress during a recession are more likely to reduce spending on inputs such as labor.

The effect of firm size on the adjustment speed of the firm with respect to R&D is somewhat puzzling. According to Jensen (1986) the executives of large mature firms that have control over large free cash flows in some cases waste them by investing in 'status symbols' like luxurious offices. Overly large R&D departments also belong to this category.

The results that imply that smaller firms invest at a higher rate both in R&D and physical capital could be attributed to the fact that they are still growing.

After replacing leverage by the interest coverage ratio in the model, we obtained results that were not very different. When this ratio takes on a high value, firms adjust their stock of knowledge more rapidly according to the version of the model that was differenced twice. In many cases the adjustment speed is above one which casts doubts on these results. Furthermore the R&D intensity of the firm did not affect the speed of adjustment of physical capital.

Finally the adjustment speed to the optimal stocks has been calculated for four typical firms with low/high leverage and firm size. Tables 3A and 3B show the results.

4.4.2 Results Obtained for the Euler Equations

Although the results based on the simple model are informative we put more faith in those obtained with a structural model. The estimates of the Euler equations (3.10a,b) can be found in table 4. Since interacting adjustment cost terms were found to be negligible, we maintained $\phi_{GK}=0$. Since

the firm data where recorded at the end of its fiscal year, which is chosen by the firm, they could not be matched exactly with the price information. This could spoil our estimates when we would take first differences to get rid of fixed effects. On the other hand many observations will be lost when the analysis is based on long differences of the series. Therefore we have decided to estimate the model using second differences. The choice of the instruments allows for a MA(1) error process due to measurement error. For the measurement of the stock of physical capital we estimated its replacement value according to the procedure given in Salinger and Summers (1981). Data requirements for the measurement of depreciation rates and the capital stock as well as the prices reduced the number of observations considerably.

Although we have paid much attention to measurement, specification and timing issues, the results are rather weak. In the benchmark model for ordinary investment the estimates have the right sign. The coefficient of the variable costs has a plausible value but the adjustment cost parameter is insignificant. The specification where the adjustment speed and the markup depends on leverage yields a much higher value for the Wald statistic for exclusion restrictions. This should be attributed to the fact that the coefficient of the variable costs varies across leverage classes.

The model that assumes asymmetric effects across the different phases of the business cycle fares much better. The results indicate that adjustment of the capital stock is faster during a recession.

The model for R&D was multiplied by $(R_{t-1}/G_{t-1})^{1-\nu}$ before adding time dummies. We fixed δ^G at 0.15, g at 0.05 and ν at 0.20. Assuming a Cobb-Douglas technology, the measurement of the marginal productivity of R&D boils down to estimation of its elasticity w.r.t. output. Hall (1993) computed estimates of this parameter using a production function approach and found for some industries in the scientific sector in the 1981-1985 period values close to zero and even negative values. This *could* be due to a variety of problems. Two potential causes are negligence of dynamics and heterogeneity in the elasticities w.r.t. output. The cost share of R&D differs considerably across firms. Therefore the R&D model was also estimated with the R&D elasticity replaced by its cost share. Because we wanted to allow for the possibility of absense of adjustment costs, we used sales as LHS variable. The cost of goods sold variable is likely to explain a large part of sales, leaving insufficient information to identify the adjustment parameter of R&D. To circumvent this problem, we decided to drop the cost of goods sold variable from the model.

Table IIIa

Adjustment Speed based on model (3.1, 3.2)*

(implied by estimates of 2 × differenced version)

$$\lambda_{it} = \lambda_0 + \lambda_1 \text{leverage}_{it} + \lambda_2 \text{size}_{it}$$

Physical Capital		
	Expansion	
LEV / SIZE	LOW	HIGH
SMALL	0.676	0.958
BIG	0.978	1.260
	Recession	
LEV / SIZE	LOW	HIGH
SMALL	1.522	1.390
BIG	1.614	1.482
Knowledge Capital		
	Expansion	
LEV / SIZE	LOW	HIGH
SMALL	0.796	0.324
BIG	1.416	0.944
	Recession	
LEV / SIZE	LOW	HIGH
SMALL	0.528	0.771
BIG	0.069	0.332

* The adjustment speed function is evaluated in ± 1 standard deviation of the leverage and firm size respectively. Note that the average values are 0.

Table IIIb

Adjustment Speed based on model (3.1, 3.2)*
(implied by estimates of 1× differenced version)

$$\lambda_{it} = \lambda_0 + \lambda_1 \text{leverage}_{it} + \lambda_2 \text{size}_{it}$$

Physical Capital		
	Expansion	
LEV / SIZE	LOW	HIGH
SMALL	0.940	0.542
BIG	0.646	0.248
	Recession	
LEV / SIZE	LOW	HIGH
SMALL	0.690	0.884
BIG	0.522	0.716
Knowledge Capital		
	Expansion	
LEV / SIZE	LOW	HIGH
SMALL	0.063	0.062
BIG	0.054	0.053
	Recession	
LEV / SIZE	LOW	HIGH
SMALL	0.334	0.367
BIG	0.271	0.304

* The adjustment speed function is evaluated in ± 1 standard deviation of the leverage and firm size respectively. Note that the average values are 0.

Since results didn't improve/change when the specification that takes the heterogeneity of the R&D elasticity into account was used, we report in table 4 the results for the basic version. The estimates for the model without dummy interaction are insignificant. Only the model that allows for asymmetrical behavior across the business cycle performs better. The parameters have the right sign and their order of magnitude seems plausible. Again we find that the adjustment speed is significantly higher during a recession. Because the instruments are based on observations from at least three periods (years) ago, the high second order serial correlation does not lead to inconsistency of the estimates.

Finally when estimating the model for two subsamples with one subsample containing the highly leveraged firms during the recession and the other subsample the remaining observations, the test statistics indicated that the parameters we are interested in are far from significantly different from zero.

4.5 Conclusions

In this paper we have put the financial accelerator hypothesis to the test once more. However we hardly found evidence in support of this theory. The finding that smaller firms adjust faster to new conditions could reflect that their technology is more flexible. Moreover, leverage did not affect ordinary investment and R&D at all, even when we made an attempt to control for debt capacity. However, the results suggested that there are differences in the adjustment processes of both ordinary and knowledge capital across stages of the business cycle.

The absense of an (depressing) effect of leverage on investment should be reassuring for the policymakers. However, most of the increase in corporate leverage took place after 1987, the end of the sample period. A substantial part of this increase was related to takeovers, buy-outs and other corporate restructuring activities. This in turn suggests that many firms still could afford to increase their leverage, without immediately getting into financial distress after an adverse shock to the economy.

Some reservations concerning the conclusion that firms adjust their stocks of capital faster during a recession are in place. One could argue that in the structural models the true marginal productivity of capital will only be measured correctly during an expansion, when the firm operates at full

capacity. By adopting the Cobb-Douglas specification for the technology of the firm, we measure the marginal productivity of an input by its average productivity. This approach is likely to overestimate the marginal productivity during a recession. Moreover, during a recession, the Cobb-Douglas formula of the marginal productivity in a way already accounts for (convex) adjustment costs: since the formula overestimates marginal productivity, it implies that it is optimal to adjust the capital stock downward to a lesser extent than the true marginal productivity would imply. In other words, the 'smoothed' marginal productivity series induces the same behavior in the series of the stock of capital. When the true adjustment cost function is stable over time, the misspecification of marginal productivity leads to overestimating the speed of adjustment during the recession. On the other hand, not the actual marginal productivity, but the expected marginal productivity of capital matters. Since it is difficult to predict the state of the economy more than one year ahead, the average productivity series might not be a bad proxy for the expected marginal productivity after all when there is a considerable lag between the decision to invest and the time at which the investment becomes productive.

The finding for the partial adjustment model for R&D that the adjustment speed of R&D is higher during a recession, could also be interpreted in at least one other way. It might just be a confirmation of the finding of Meyer and Kuh (1957), that investment is more sensitive to liquidity during a downturn of the economy.

We believe that the fragility of the results for the Euler equation for R&D is partly related to the problems that exist with respect to the measurement of the stock of R&D. The true stock of knowledge only includes successful R&D. The way we constructed the stock of knowledge, namely by applying the perpetual inventory method to the series of R&D expenditures, assumes that all R&D activities have the same rate of success. In reality, the invention process is of a highly stochastic nature. Furthermore, the stock of knowledge should also include spillovers from other firms etcetera.

To get a better understanding of the dynamics of the R&D investment decision, we should look for better measures of its productivity. Much is still unkown about the lags between investment in R&D and the results. Furthermore, although R&D activities are eventually aimed at increasing the value (sales) of the firm, investment in R&D might be driven/better explained by a short term measure of success of R&D, for instance patents.

Table IV

GMM Estimation Results model (3.11a,b) *(→)

	PHYSICAL CAPITAL (second differences)		R & D (first differences)
NO SPLIT			
ζ_1^K	1.3514 (0.1361)	ζ_2^G	387.09 (354.18)
ζ_2^K	0.6682 (1.5900)	ζ_3^G	194.60 (134.87)
ζ_5^K	-2.2384 (1.4603)	ζ_5^G	- 2.968 (54.026)
WALD	110.00		2.511
(D.F.)	(3)		(3)
SARGAN	5.464		4.634
(D.F.)	(4)		(5)
m_1	2.19	m_1	-0.432
m_2	-0.63	m_2	0.260
m_3	-1.30	m_3	0.146
SPLIT BY LEVERAGE			
ζ_1^K	1.5029 (0.1542)	ζ_2^G	510.97 (280.01)
ζ_2^K	-1.4801 (1.2767)	ζ_3^G	253.44 (116.53)
ζ_5^K	-0.2383 (0.7840)	ζ_5^G	-13.233 (12.339)
$S\zeta_1^K$	-0.3071 (0.1634)	$S\zeta_2^G$	-306.71 (232.28)
$S\zeta_2^K$	0.6445 (1.6399)	$S\zeta_3^G$	- 73.92 (114.80)
$S\zeta_5^K$	-0.2994 (0.8970)		
WALD	1098.54		28.600
(D.F.)	(7)		(5)
SARGAN	12.92		5.050
(D.F.)	(8)		(12)
DISTANCE	4.696		2.228
(D.F.)	(3)		(2)

Table IV continued

PHYSICAL CAPITAL (second differences)		R & D (first differences)	
m_1	2.23	m_1	-0.312
m_2	-1.43	m_2	0.514
m_3	-1.10	m_3	-0.148
ASYMMETRY			
ζ_1^K	1.2600 (0.2186)	ζ_2^G	429.17 (181.76)
ζ_2^K	2.1345 (1.8605)	ζ_3^G	176.37 (105.15)
ζ_5^K	-3.0842 (3.0495)	ζ_5^G	26.541 (21.093)
$A\zeta_1^K$	0.2830 (0.2661)	$A\zeta_2^G$	-966.98 (266.80)
$A\zeta_2^K$	-4.9898 (1.8405)	$A\zeta_3^G$	-498.06 (214.28)
$A\zeta_5^K$	-1.6162 (3.2225)		
WALD (D.F.)	143.44 (7)		29.80 (5)
SARGAN (D.F.)	6.595 (8)		13.62 (12)
DISTANCE (D.F.)	9.226 (3)		21.85 (2)
m_1	2.25	m_1	-2.11
m_2	-1.31	m_2	-3.76
m_3	-1.58	m_3	0.69

* See Appendix 4.B for Regression Equations and Instruments.

Obs.321, # Firms 55 Period 1978-1986, Time and Regime Dummies have been included, HAC Standard Errors between parentheses, Wald Test for joint significance of nontrivial regressors, Distance Test for Constancy of Parameters across Regimes, m_i is test for autocorrelation of i-th order ~ N(0,1). $A\zeta_i^F$, $S\zeta_i^F$ are deviations from values of parameters calculated for the expansion stage of the business cycle and high leverage subsample respectively.

Appendix 4.A: Derivation of the formula of the constant c in (3.5) and (3.10a)

It is assumed in the model that R&D capital obeys the following transition equation

$$G_t = cG_{t-1}^{1-V} R_{t-1}^{V} \tag{A.1}$$

Now suppose that R&D expenditures grow at rate g

$$R_t = (1+g)^t R_0 \tag{A.2}$$

and that the R&D stock series from the dataset has been constructed according to

$$G_t = (1-\delta^G)\, G_{t-1} + R_{t-1} \tag{A.3}$$

Solving (A.3) recursively and using (A.2) yields

$$G_t = \left(\frac{1}{\delta^G + g}\right) (1+g)^t R_0 \quad \text{for large t} \tag{A.4}$$

Finally substituting (A.4) in (A.1) gives

$$G_t = c \left(\frac{1}{\delta^G + g}\right)^{1-V} (1+g)^{t-1} R_0 = \left(\frac{1}{\delta^G + g}\right) (1+g)^t R_0 \tag{A.5}$$

or

$$c = (1+g)\left(\frac{1}{\delta^G + g}\right)^{V} \tag{A.6}$$

Appendix 4.B: Regression Equations and Instruments

Model (after taking first differences):

$$\Delta \ln X_{it} = -\mu_1 \lambda_{it} + \mu_0 \lambda_{it} \Delta \ln S_{it} + (1-\lambda_{it}) \Delta \ln X_{it-1} + \Delta u_{it} \tag{3.1}$$

$$\lambda_{it} = \lambda_0 + \lambda_1 \text{LEVerage}_{it} + \lambda_2 \text{SIZE}_{it} \tag{3.2}$$

$$\tilde{\lambda}_{it} = \exp(\lambda_{it})/(1 + \exp(\lambda_{it}))\ ) \tag{3.2'}$$

Define ML ≡ Leverage, MS ≡ Firmsize (deviations from the sample mean),
Regression equation (for R&D) in first differences
assuming $G_{it} = (1-\delta^G)G_{it-1} + R_{it}$:

$$\left[\frac{R_t}{G_{t-1}}\right] - \beta_6 ML_{t-2} - \beta_7 MS_{t-2} - \beta_5\beta_4\left[\frac{\Delta S_t}{S_{t-1}}\right] - \beta_5\beta_2 ML_{t-2} * \left[\frac{\Delta S_t}{S_{t-1}}\right]$$

$$- \beta_5\beta_3 MS_{t-2} * \left[\frac{\Delta S_t}{S_{t-1}}\right] - \left[1 - \beta_4 - \beta_2 ML_{t-2} - \beta_3 MS_{t-2}\right] * \left[\frac{R_{t-1}}{G_{t-2}}\right]$$

$$+ \text{time and industry dummies} = w_t + \gamma_1 w_{t-1} \tag{3.1'}$$

(The error term of the twice differenced regression equation is
also assumed to follow a MA(1) process)

Instruments:

Define ML ≡ Leverage, MS ≡ Firmsize (deviations from the sample mean),
INDP ≡ Industrial production, CAPUT ≡ Capacity utilization,
FEDR ≡ Discount rate of Federal Res. Bank of NY, CPI ≡ Inflation rate.
R_{-3}/G_{-4}, R_{-4}/G_{-5} , ML_{-3}, MS_{-3}, $\Delta S_{-3}/S_{-4}$, $\Delta S_{-4}/S_{-5}$, $ML_{-3} \times (\Delta S_{-3}/S_{-4})$,
$MS_{-3} \times (\Delta S_{-3}/S_{-4})$, $INDP_{-2}$, $CAPUT_{-2}$, $FEDR_{-2}$, CPI_{-2}, $INDP_{-3}$, $CAPUT_{-3}$,
$FEDR_{-3}$, CPI_{-3}, same variables as above × recession dummy,
time dummies and industry dummies.

R&D:

(3.10a')

$$\left\{\frac{S_t}{G_t}\right\} - \zeta_2^G\left\{c(1+\rho)\left[\frac{R_{t-1}}{G_{t-1}}\right]^2\left[\frac{G_{t-1}}{G_t}\right] - (c(1-\nu) + \tfrac{1}{2}(\nu/\theta))\left[\frac{R_t}{G_t}\right]^2\right\}$$

$$- \zeta_5^G\left\{\left\{c(1+\rho)p^G_{t-1}\left[\frac{R_{t-1}}{G_{t-1}}\right]\left[\frac{G_{t-1}}{G_t}\right]\right\} - \left\{c(1-\nu)p^G_t\left[\frac{R_t}{G_t}\right]\right\}\right\}$$

$$- \zeta_3^G\left\{\left[\frac{R_t}{G_t}\right] - c(1+\rho)\left[\frac{R_{t-1}}{G_{t-1}}\right]\left[\frac{G_{t-1}}{G_t}\right]\right\} =$$

time dummies + regime dummy + firm dummies + $w_t + \gamma_1 w_{t-1}$

In the derivation of the estimating equation,

we exploited the equality $c\left[\frac{G_{t-1}}{G_t}\right] = \left[\frac{R_{t-1}}{G_{t-1}}\right]^{-\nu}$

$$\zeta_2^G = \frac{\phi_G}{(1-\psi^D)(\nu/\theta)(\eta-\alpha_K-\alpha_N)} \qquad \zeta_3^G = \frac{(1/2)\phi_G c_G}{(1-\psi^D)(\nu/\theta)(\eta-\alpha_K-\alpha_N)}$$

$$\zeta_5^G = \frac{1/(1-\tau)}{(1-\psi^D)(\nu/\theta)(\eta-\alpha_K-\alpha_N)}$$

with $\theta \equiv (1/c)^{1/\nu}$ $\quad c \equiv (1+g)\left[\frac{1}{\delta^G+g}\right]^{\nu}$ $\quad \delta^G = 0.15,\ \nu = 0.20,\ g = 0.05.$

Instruments :

$(S/G)_{t-3}$, $(S/G)_{t-4}$, $(R/G)^2_{t-4}(G_{t-4}/G_{t-3})$, $(R/G)^2_{t-3}$,
$p^G_{t-4}(R/G)_{t-4}(G_{t-4}/G_{t-3})$, $p^G_{t-3}(R/G)_{t-3}$,
$(R/G)_{t-3}$, $(R/G)_{t-4}(G_{t-4}/G_{t-3})$
same instruments as above × regime dummy,
time dummies and regime dummy.

PHYSICAL CAPITAL:

(3.10b′)

$$\left[\frac{S_t}{K_t}\right] - \zeta_1^K\left[\frac{C_t}{K_t}\right] - \zeta_2^K\left\{\left[\frac{I_t}{K_t}\right] - \frac{(1-\delta^K)}{(1+\rho)}\left[\frac{I_{t+1}}{K_{t+1}}\right] - \frac{1}{2}\left[\frac{I_t}{K_t}\right]^2\right\}$$

$$+ \zeta_5^K\left\{p_t^K - \frac{(1-\delta^K)}{(1+\rho)}\, p_{t+1}^K\right\} =$$

time dummies + regime dummy + firm dummy + $w_{t+1} + \gamma_1 w_t + \gamma_2 w_{t-1}$

$$\zeta_1^K = \frac{1}{(1-\psi^D)(\eta-\alpha_G-\alpha_N)} \quad \zeta_2^K = \frac{\phi_K}{(1-\psi^D)(\eta-\alpha_G-\alpha_N)} \quad \zeta_5^K = \frac{-\,1/(1-\tau)}{(1-\psi^D)(\eta-\alpha_G-\alpha_N)}$$

Instruments :

$(I/K)_{t-4}, (I/K)_{t-5}, (I/K)^2_{t-4}, (I/K)^2_{t-5}, (S/K)_{t-4}, (C/K)_{t-4}, p^K_{t-5} - \frac{(1-\delta^K)}{(1+\rho)} p^K_{t-4}$,

same instruments as above × regime dummy, regime dummy and time dummies.

Chapter 5

The Role of Working Capital in the Investment Process

5.1 Introduction

For investment firms rely to a large extent on internal finance especially those firms for which external finance is either too expensive or just not available. By retaining cash flows, firms accumulate the financial funds needed for investment. A considerable share of the financial assets that firms hold takes the form of so-called working capital, which consists of short term assets and short term liabilities. Working capital is needed for the day-to-day financial operation of the firm and as such is an important indicator of the liquidity of the firm.

In this chapter we investigate the sensitivity of investment in both physical capital and R&D to the presence of liquidity constraints. We assess the severity of underinvestment due to a lack of internal funds by looking at (changes in) the stock of working capital.

We derive within a formal theoretical framework of a value maximizing firm that is subject to financial constraints, the relationship between working capital and the change in the shadow value of funds. When estimating the Euler equations for investment and R&D we exploit this relationship to allow for heterogeneity in behavior due to changes in liquidity over time. Earlier papers, e.g. by Hall (1991) and Bond and Meghir (1994), have split the sample on the basis of dividend payout ratios or information on share issues.

We see several advantages to our procedure for measuring (changes in) the liquidity of the firm, which uses information on working capital, over other criteria. First, working capital is a continuous indicator of liquidity while share issues take place in a discrete fashion. Second dividends are not just the residual of cash flow that remains after all other (financial) decisions have been taken. Firms choose a dividend policy for a rather long period and are reluctant to deviate from it; a cut in dividends is often interpreted as a

bad signal about the prospects of the firm which in turn can result in a rise in the cost of external finance. Thus dividends reflect the liquidity of the firm only to a limited extent and are less variable than working capital. However like dividends, the amount of working capital that a firm holds is determined by several (firm and industry specific) considerations and not just by investment plans. This reduces the quality of working capital as an indicator of liquidity of the firm and has implications for the econometric strategy that we employ. Moreover, working capital is the sum of various components, some of which are more under control of the firm than others. The various definitions of working capital that are encountered in the literature actually give a different picture of the liquidity of the firm.

In addition to Euler equations we estimate a version of a Q model, that allows for different investment behavior across financial regimes. By using a different approach than others did, namely the endogenous switching regression methodology, our results add to the existing small empirical literature that focuses on the relationship between the accumulation of working capital and investment and is based on the Q model: we will split the sample by the sign of the change in working capital and test for differences between the estimates of the parameters which are obtained for the subsamples.

The sample we employ for the inference consists of data from U.S. firms in the scientific sector. This sample allows us to study investment in R&D. Furthermore as the firms in the sample are R&D intensive, they face higher cost of external finance and therefore will rely more heavily on internal funds. This feature of the sample makes it especially suitable to investigate the role of working capital in the investment process.

This chapter proceeds as follows. In section 2 we discuss the role of working capital within the firm and in particular in the investment process in more detail. In section 3 we outline the econometric framework and specify the hypotheses that we intend to test. Section 4 describes the sources of the data we used and the properties of the data by means of simple statistics. Section 5 then presents the empirical results and discusses them. Section 6 concludes.

5.2 The Role of Working Capital in the Investment Process

For operating a firm working capital is as crucial as fixed capital. It is the net amount of short term assets — current assets minus current liabilities — of the firm which gives it some latitude at several activities.

For instance, by holding inventories at various stages of the production process the firm can run larger batches and is less vulnerable to strikes, and the presence of accounts receivable on the balance sheet reflects the fact that the firm is willing to sell goods to customers that are solvent but short of cash.

Working capital is a prime measure of liquidity of the firm. Current assets include financial assets such as cash money and accounts receivable but also real assets such as inventories since it is thought that they can relatively easily be converted into cash. Current liabilities consist of (accounts) payable(s) and short term debt.

The various parts of working capital display their own patterns over the business cycle. When a firm is experiencing a negative shock to demand, its inventories of final products will generally rise. Later on, when it becomes clear that this demand shock was the beginning of a recession and the firm is in financial distress, the firm will try to shed inventories of all kinds [1], to collect accounts receivable, and try to postpone payments of debts. That is, as the recession gets worse, the liquidity of firms measured as working capital decreases as does cash flow. At the aggregate level of the manufacturing sector both in 1975 and in 1982 working capital declined sharply; some components, such as accounts receivables and inventories even fell considerably relative to sales.

The decline in working capital affects investment directly since it implies a fall in internal funds, and indirectly by raising the cost of external funds. Bernanke and Gertler (1988) and Gertler (1989) argue that the agency cost of external finance depends on the quality of the balance sheet of the firm. When its liquidity decreases or when prospects concerning future sales deteriorate, the cost of external finance rises. Eckstein and Sinai (1986) found that at the end of the recession and at the beginning of a recovery firms try to rebuild their debt capacity by accumulating short term financial assets in order to be able to borrow at acceptable rates when they need funds for investment. According to them this reliquefication characterizes a separate phase of the business cycle that precedes the period in which firms start to invest again.

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[1] A firm will also reduce inventories of materials during the recession as it will produce less.

It is conceivable that firms also save working capital in order to make sure that it can carry out an investment plan that takes years without interruption due to lack of cash.

Depending on the structure of the adjustment costs, working capital has still another effect on the investment process beyond those mentioned above. It will be used to smooth investments in the case of convex adjustment costs. If a fixed costs component dominates, investments decisions will seem irreversible. As Whited (1991) points out the height of the opportunity costs of reversing the investment decision varies with the cost of external finance which in turn depends on the availability of working capital inter alia. From the irreversability literature [2] we know that the higher the sunk costs, the longer a firm will wait to execute its investment plan ceteris paribus. Thus the size of the stock of working capital influences the timing (delay) of investment. Notice that working capital can be used for smoothing investment because it is in contrast to physical capital perfectly reversible.

The amount of working capital that firms will hold for instance in order to make sure that investment plans don't have to be interrupted depends among other things on their reputation in capital markets. For firms that are regarded as being of both high long term and high short term credit quality, Calomiris et al. (1994) find that they have lower stocks of inventories and financial working capital and in addition that these stocks are less sensitive to cash flow fluctuations. The latter finding is interpreted by them as follows. Firms of higher credit quality don't need to accumulate working capital as a buffer against fluctuations in cash flow as they can easily obtain external funds at favorable terms. Furthermore they show that given a high (long term) bond rating, only firms of large size, with low earnings variance, high cash flows and/or large stocks of liquid assets have access to the commercial paper market. The former characteristics however seem sufficient for firms to be able to issue commercial paper successfully given the fact that they have less working capital on average.

The firm controls the various components of working capital to a different extent. In general it will have more control over inventories of materials than over inventories of finished products or accounts receivable. Moreover, the bank might set a limit to short term debt or demand a minimum

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[2] See the survey of Pindyck (1991).

level of cash. As a consequence the interpretation of working capital as a measure of liquidity depends crucially on its definition. For instance high working capital defined as cash minus short term debt, might actually be a sign of low liquidity when it reflects restrictions imposed by the bank.

The empirical literature on the interaction between investment and decisions on working capital we are aware of is very limited. Whited (1991) put the reliquefication theory of Eckstein and Sinai to a test. Allowing coefficients to vary over time and controlling for demand by including output, she found that lags of working capital contributed significantly to a Q regression of investment and that in accordance with the theory investment was especially sensitive to the level of working capital [3] just after the trough of the business cycle (in 1983). Moreover when she split the sample using the criterion of whether firms have a bond rating from Moody's or not, this particular pattern in the coefficient of working capital was only found for firms of low credit quality. Fazzari and Petersen (1994) view working capital as a use of funds which is competing with fixed investment but also as a means (source) to smooth investment such that fluctuations in cash flow will not be transmitted fully to investment. Their empirical results indicate that when in addition to cash flow, the (simultaneous) change in working capital enters a Q regression model of ordinary investment, the coefficient of cash flow rises while the sign of the coefficient of the investment in working capital is negative. This should not be interpreted as evidence that investment and the change in working capital are negatively correlated. Their findings are consistent with the following interpretation. The change in working capital takes out (part of) the transitory component of cash flow such that the permanent component remains which determines investment primarily (through the liquidity effect).

In fact, if a firm is liquidity constrained, a positive (negative) shock to cash flow will increase (decrease) both the stock of working capital and investment. If the shock is transitory, the extent of investment smoothing determines the actual size of the change in working capital. If the shock was negative (and transitory), the firm will not reduce working capital when it has reached some minimum level necessary for operating the firm but instead reduce investment more.

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[3] Whited measures working capital as current assets minus inventories, receivables and short term debt including the current portion of long term debt.

5.3 The Econometric Framework

To study the role of working capital in the investment process, we calculate the correlations between financial working capital [4] and ordinary investment as well as R&D, and estimate reduced form and structural models to test specific theoretical assumptions concerning their interrelation. More in particular we are interested in the signs of the simple correlations between some key variables of the firm and their patterns over time. That information can throw some light on questions as to whether working capital is a (temporary) depository of funds kept to obtain external finance at lower rates or to smooth investment, that is to act as a buffer to smooth out fluctuations in cash flow (or other sources of funds), or merely a use of funds competing with investment. In the former case we expect a positive correlation between changes in working capital and changes in sales and a (slightly) positive correlation between investment and changes in working capital, while in the latter case the negative correlation that is inherent in competition (for funds in this case) dominates the relation between working capital and investment. If working capital is held for precautionary reasons, for instance in order to make sure that investment projects can be completed, changes in sales and working capital might be negatively correlated, especially when changes in sales persist over time.

The relationships between ordinary investment, R&D and changes in financial working capital are further investigated on the basis of two models that are widely used in empirical economics to explain investment: the Q model and "the Euler equation" model. They are related to each other as the first is obtained by solving the Euler equation forward. However, the way in which the expected present value of the discounted stream of marginal profits (marginal Q) is measured distinguishes the models from each other: by using information from the financial markets, expectations are measured directly rather than dealt with in an econometric way.

In sub-section 5.3.1 we derive a version of the Euler equations for physical capital and R&D that allows for changes in liquidity over time. In the next sub-section we outline an estimation strategy for Q models of investment that involves a split of the sample according to whether the liquidity of the

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[4] Below by working capital we mean financial working capital as it was measured by Whited (1991), and which will be defined formally in (3.1).

firm improves or not. In both models, liquidity is measured by the shadow value of funds, which is unobservable. However, in sub-section 5.3.1 we will establish a link between the changes in liquidity and working capital, which is instrumental for estimating both types of models. The exposition of the models, that will be used to investigate the role of working capital in the investment process, is followed by a discussion of econometric problems that have to be dealt with at the estimation stage. First we give our definition of financial working capital

$$W_t = CASH_t - STDEBT_t \tag{3.1}$$

that is, financial working capital equals cash, short term investments, and prepaid expenses less short term debt and the current portion of long term debt. Like Whited (1991), we exclude both receivables and payables from the definition. Financial working capital, as we define it, is a better variable to stratify by, because changes in inventories are determined by many (nonfinancial) considerations, such as optimization of the production process by producing in bunches for instance, and unexpected shocks in demand. Furthermore to the extent that the firm controls net receivables, they are not only used as a financial buffer but also to further sales.

5.3.1 The Euler Equations

In this subsection we derive the Euler equation models for investment and R&D and we explicitly establish their relation with working capital. The firm is assumed to maximize the expected value of the discounted stream of dividends subject to accumulation constraints on the stocks of capital and financial constraints. One constraint demands that working capital does not get below some minimum level $\underline{W}_t$. This value can be thought of as the minimum amount that is necessary to run the firm or a lower bound that is stipulated in the debt contract with the bank. The dividends D_t are given by [5]

$$\begin{aligned} D_t = (1-\tau)(\Pi(K_t,G_t) - AC_t(I_t,K_t,G_t,R_t) - AGC(B_t,K_t,G_t)B_t - p_t^G R_t) + \\ \Delta B_t + V_t^N - \Delta W_t - p_t^K I_t + \Delta(PAYOTH_t - RECEIV_t - INV_t) \end{aligned} \tag{3.2}$$

where $\Pi_t(.)$ is the long run revenue function, $AC_t(.)$ the adjustment cost

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[5] We omit the subscript indicating the firm.

List of Variables

G_t	stock of knowledge (R&D) capital at the end of period t
K_t	stock of physical capital at the end of period t
R_t	R&D expenditure during period t
I_t	ordinary investment during period t
S_t	sales at the end of period t
B_t	outstanding long term debt at the end of period t
D_t	dividends paid during period t
V^N_t	new shares during period t
W_t	(financial) working capital at the end of period t
INV_t	(total) inventories at the end of period t
$CASH_t$	cash at the end of period t
$RECEIV_t$	accounts receivable at the end of period t
$STDEBT_t$	short term debt at the end of period t
$PAYOTH_t$	accounts payable and other short term liabilities (t)

function and $AGC_t(.)$ the interest rate schedule. They will be specified below. τ is the corporate tax rate. Table 1 gives a list of definitions of the variables used. p^G and p^K are the real costs of knowledge and physical capital. The last term in the flow of funds constraint (3.2) containts the variables that we left out from our definition of working capital. We will assume that they do not affect the value of the firm and can be ignored in the analysis. The firm's maximization problem can now be stated as follows

$$\underset{I,R,V^N,D,\Delta B,\Delta W}{\text{Max}} \quad E_t(V_t) = E_t \sum_{s=0}^{\infty} \left[1+\frac{\rho}{(1-\omega)}\right]^{-(t+s)} \left[\frac{(1-q)}{(1-\omega)} D_{t+s} - (1+\Xi_{t+s})V^N_{t+s}\right] \tag{3.3}$$

subject to (3.2) and the following constraints

$$\lambda^K_t \qquad I_t = K_t - (1-\delta^K)\, K_{t-1}\,, \tag{3.4a}$$

$$\lambda^G_t \qquad R_t = G_t - (1-\delta^G)\, G_{t-1}\,, \tag{3.4b}$$

$$\xi^B_t \qquad B_t = \Delta B_t + B_{t-1}\,, \tag{3.4c}$$

$$\xi^W_t \qquad W_t = \Delta W_t + W_{t-1}\,, \tag{3.4d}$$

$$d_t \qquad D_t \geq 0, \tag{3.4e}$$

$$v_t \qquad V^N_t \geq \underline{V}^N_t \tag{3.4f}$$

$$\eta_t \qquad W_t \geq \underline{W}_t\,, \tag{3.4g}$$

where ρ is the investor's required after-tax rate of return, ω is the capital gains tax rate and q is the personal income tax rate. This maximization problem assumes that when the shareholders issue new shares to the company, they must pay a premium Ξ in the form of a decrease in value of their existing shares, because of the existence of 'lemons' in the equity market (see Akerlof, 1970). The first column of (3.4) shows the current value Langrange or Kuhn-Tucker multipliers corresponding to the constraints. μ_t is the Lagrange multiplier associated with (3.2). The transition equations for B_t and W_t hold trivially but are included for the sake of completeness. Before we give the first order conditions, we specify the revenue function, the adjustment cost function and the interest rate schedule.

The long run revenue function is given by

$$\Pi(K_t,G_t) = CD(K_t,G_t) = \alpha_{0,t} K_t^{\alpha_K} G_t^{\alpha_G} \tag{3.5}$$

Adjustment cost function

$$AC(I_t,K_t,I_t,R_t) = \tfrac{1}{2}\,\phi_K\,(I_t/K_t - c_K)^2\,K_t + \tfrac{1}{2}\,\phi_G\,(R_t/G_t - c_G)^2\,G_t \tag{3.6}$$

Interest rate schedule (agency cost function)

$$AGC(B_t,K_t,G_t) = \zeta_0 + \tfrac{1}{2}\,[\zeta_K + \zeta_G\,K_t/G_t]\,B_t/K_t \tag{3.7}$$

The long run revenue function corresponds to a Cobb-Douglas technology. As the revenue elasticities do not have to add up to one, it allows for nonconstant returns to scale and the possibility that the firm has some market power in the output market. The specification that we choose to measure the adjustment costs is ubiquitously in the literature. In the interest rate schedule the cost of debt is assumed to depend on the importance of agency costs considerations. The higher the debt, the more likely that a firm defaults. Therefore bondholders will demand a higher risk premium as debt increases. Furthermore when most of the firm's assets are intangible, it will have less collateral to offer to the bank or any other creditor that can be sold in case of a bankruptcy. Thus we expect that ζ_G is negative and that the other coefficients in AGC(.) are positive and also that $[\zeta_K + \zeta_G\,K_t/G_t]$ is positive.

The first order conditions for the control variables we are interested in I_t, R_t, V_t^N, D_t, ΔB_t, and ΔW_t are the following

$$\lambda_t^K - \mu_t[(1-\tau)(\partial AC_t/\partial I_t) + p_t^K] = 0 \tag{3.8a}$$

$$\lambda_t^G - \mu_t[(1-\tau)(\partial AC_t/\partial R_t) + p_t^G] = 0 \tag{3.8b}$$

$$\tilde{\mu}_t + \tilde{v}_t = (1 + \Xi_t) \quad \tilde{v}_t(V_t^N - \underline{V}_t^N) = 0 \quad \tilde{v}_{t+s} = v_{t+s}(1 + \frac{\rho}{1-\omega})^s \tag{3.8c}$$

$$\tilde{\mu}_{t+s} = \mu_{t+s}(1 + \frac{\rho}{1-\omega})^s$$

$$\tilde{\mu}_t - \tilde{d}_t = \frac{(1-q)}{(1-\omega)} \qquad \tilde{d}_t D_t = 0 \qquad \tilde{d}_{t+s} = d_{t+s}(1 + \frac{\rho}{1-\omega})^s \tag{3.8d}$$

$$\mu_t - \xi_t^B = 0 \tag{3.8e}$$

$$\mu_t - \xi_t^W = 0 \tag{3.8f}$$

The first order conditions for the state variables K_t, G_t, B_t, and W_t are (after eliminating λ_t^K, λ_t^G, ξ_t^B, and ξ_t^W using equations (3.8a,b,e,f))

$$(1 + \frac{\rho}{1-\omega}) \frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} \Big[\alpha_K \Pi_{t-1}/K_{t-1} + \tfrac{1}{2}\phi_K (I_{t-1}/K_{t-1})^2 - \phi_K I_{t-1}/K_{t-1} \tag{3.9a}$$
$$+ \xi_K (B_{t-1}/K_{t-1})^2 - \frac{1}{1-\tau} p_{t-1}^K\Big] + \phi_K(1-\delta^K) I_t/K_t + \frac{1-\delta^K}{1-\tau} p_t^K + f_i + s_t = w_{it}$$

$$(1 + \frac{\rho}{1-\omega}) \frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} \Big[\alpha_G \Pi_{t-1}/G_{t-1} + \tfrac{1}{2}\phi_G (R_{t-1}/G_{t-1})^2 - \phi_G R_{t-1}/G_{t-1} \tag{3.9b}$$
$$+ \xi_G (B_{t-1}/G_{t-1})^2 - \frac{1}{1-\tau} p_{t-1}^G\Big] + \phi_G(1-\delta^G) R_t/G_t + \frac{1-\delta^G}{1-\tau} p_t^G + f_i + s_t = w_{it}$$

$$(1 - (1-\tau)[\zeta_0 + [\zeta_K + \zeta_G K_t/G_t] B_t/K_t]) (1 + \frac{\rho}{1-\omega}) \frac{\tilde{\mu}_t}{\tilde{\mu}_{t+1}} = 1 \tag{3.9c}$$

$$\tilde{\mu}_{t+1} = (1 + \frac{\rho}{1-\omega}) [\tilde{\mu}_t + \tilde{\eta}_t] \qquad \tilde{\eta}_t(W_t - \underline{W}_t) = 0 \tag{3.9d}$$

$$\tilde{\eta}_{t+s} = \eta_{t+s}(1 + \frac{\rho}{1-\omega})^s$$

or

$$\mu_{t+1} = [\mu_t + \eta_t] \qquad \eta_t(W_t - \underline{W}_t) = 0 \tag{3.9d'}$$

$$d(\mu_{t-1}/\mu_t)/d\eta_{t-1} = -1/\mu_t < 0 \tag{3.10}$$

To understand the implications of the model, we will give an interpretation of some of the first order conditions, notably those pertaining to the financial variables (3.8c,d) and (3.9c,d).

When W_t equals the lowerbound $\underline{W}_t$, the shadow value of working capital is negative. The more the operation of the firm is hampered by the constraint on working capital, the lower η_t becomes. It follows from (3.10) that when η_t decreases, next year's investment becomes more sensitive to the marginal profit of last year (the term between brackets in 3.9a,b).
Equations (3.8c) and (3.8d) give rise to (at most) four financial regimes:

1 $d > 0$ and $v = 0$: no dividends and issue of new shares
2 $d > 0$ and $v > 0$: no dividends and no new shares
3 $d = 0$ and $v > 0$: dividends and no new shares
4 $d = 0$ and $v = 0$: dividends and issue of new shares

The fourth regime is not feasible as long as $q > \omega$ and $\Xi_t \geq 0$ which was the case in the period in which the observations were collected that will be used for the inference.

Note that $(1-q)/(1-\omega) \leq \tilde{\mu}_t \leq 1 + \Xi_t$. When a firm ceases to pay dividends or starts to issue new shares, $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ drops below one and investment becomes less sensitive to last period's marginal profit. Also when the firm is in the second regime in two adjacent periods, $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ can fall below one : when the liquidity of the firm decreases, $\tilde{\mu}$ increases.

According to (3.8d) the value of a dollar inside dividend paying firms is less than a dollar, that is $\tilde{\mu}$ is at its minimum level $(1-q)/(1-\omega) < 1$. Due to tax laws, which say that the rate of personal income taxes is higher than the capital gains tax rate, funds are trapped within the firm when $(1-q)/(1-\omega) < \tilde{\mu} < 1$ (see Auerbach, 1984): it is not in the interest of the shareholders to pay dividends, although the firm does not have good investment opportunities. According to Jensen (1986) the availability of these so-called free cash flows (funds for which $\tilde{\mu} < 1$ holds) might lead to overinvestment. Only in case $\tilde{\mu} > 1$ the firm is liquidity constrained: a dollar invested in the firm would yield more than a dollar.

Equation (3.9d') suggests that the shadow price of the flow of funds constraint (3.2) (μ) remains constant (thus $\tilde{\mu}_{t-1}/\tilde{\mu}_t < 1$) when the working capital constraint was easily satisfied in period t-1. Since working capital above the minimum level $\underline{W}_t$ hardly yields any income to the firm (in fact not at all according to our model), it will be used to lower the debt burden. Even if the firm has no debt, as long as ζ_0 the intercept in the interest rate schedule is positive, η_t will be negative and W_t equals $\underline{W}_t$. In other words changes in W_t reflect changes in $\underline{W}_t$.

The Euler equations (3.9a) and (3.9b) cannot be estimated as they contain the unobserved ratio of shadow values $\tilde{\mu}_{t-1}/\tilde{\mu}_t$. However the other restrictions provide some information on their probable value. For example the first order condition for debt (3.9c) was exploited by Whited (1992) [6]. We will focus on (3.9d). However the shadow value of working capital constraint is also unobservable. It will be related to observables in the spirit of MaCurdy's (1981) approach [7]. We hypothesize that η depends on the value of $\underline{W}_t$ [8] . The sign of this relationship is ultimately an empirical matter, but we expect it to be negative. An (forced) increase in working capital — for example demanded by the bank — hurts more when a firm already holds a large stock of working capital (relative to its other assets) on which it earns no return, than when the initial level of working capital is relatively low. Or put differently: a dollar invested in working capital cannot be invested in, say, physical capital. As investment projects are chosen in order of their expected returns, a firm with relatively much working capital is likely to forgo a

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[6] Her approach to incorporating agency costs of debt in the model differs from our treatment. She specifies an inequality constraint on debt $B_t \leq \underline{B}_t$ and then obtains a first order condition for debt that includes the Kuhn-Tucker multiplier. To measure the unobservable KT multiplier she relates it to factors that are assumed to influence the cost of debt.

[7] In his pioneering paper he related the unobservable shadow value of the wealth constraint in a life-cycle model of consumption and labor supply to observables such as lifetime wage, initial assets et cetera.

[8] Of course it also depends on variables of which we know that they determine μ_t and μ_{t+1}. However our objective is to identify additional variables that determine the ratio μ_t/μ_{t+1} by exploiting its relation with η_t .

project with a higher return than the firm with less working capital. Or from still another perspective, the firm with much working capital has to make a profit with less physical and knowledge capital. Thus we expect that

$$d\eta_t/d(\underline{W}_t/K_t) < 0 \tag{3.11}$$

As we noted above, an entrepreneur that maximizes the value of the firm will set W_t equal to $\underline{W}_t$. By combining (3.10) and (3.11) we have found another way to measure the ratio of the shadow values of funds in two consecutive periods that can be exploited in order to estimate the Euler equations. To this end we could add the following equation to the model that can be substituted in the Euler equations for physical and knowledge capital (3.9a,b)

$$\frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} = \vartheta_t + \delta(W_{t-1}/K_{t-1} - \overline{W_{t-1}/K_{t-1}}) \tag{3.12}$$

Note that according to the theory outlined above, $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ is positively related to the level of W_{t-1}/K_{t-1}. We included deviations from the mean in (3.12) to deal with heterogeneity among firms: for some firms (industries) the average value of W_{t-1}/K_{t-1} will be lower, for other firms (industries) it will be higher. The time dummies track aggregate changes in the liquidity of firms as far as they are not reflected in working capital.

Before we estimate the models we must deal with the individual effects. If they are correlated with RHS variables, they cause biases in the estimates. To avoid this, the individual effects (f_i) will be removed by taking differences of the equations. Since the coefficients in the Euler equations are varying over time because of the $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ factor, this is not equivalent to taking differences of the variables (see also Holtz-Eakin, Newey and Rosen (1988)).

Both in the Euler equations and in the Q model, current investment I_t/K_t (R_t/G_t) is the dependent variable. Some of the RHS variables, notably lagged investment, Q, sales and debt, are endogenous though predetermined. However after taking differences of the equations — whether they be taken vis-à-vis the first lagged equation or the most distant lagged equation or the mean of lagged equations,— the lags of these variables will be correlated with the error term. Therefore we have to rely on an instrumental variable type

estimator or a Generalized Method of Moments estimator. In order to exploit as many orthogonality conditions as possible, we take first differences. Furthermore, our choice of the instruments will allow for measurement errors that follow a low order moving average process. Due to the panel structure of the data we are able to impose separate moment conditions for each period. As was pointed out by Arrelano and Bond (1991), in this manner we avoid problems due to nonstationarity of the data generating processes. Finally given the set of the instruments, the optimal weighting matrix that is used by GMM takes heteroskedasticity — both across firms and time — and the correlation structure of the errors over time into account. Since most of the correlation between errors corresponding to different firms is likely to be due to aggregate effects, we deal with this by including fixed time effects into the regression equations.

The specifcation for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ in (3.12) has two drawbacks. First, for large changes in working capital, the value of $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ can become negative. This is conflicting with the theory. Second, the model is perhaps too parsimonious. Apart from working capital, other (unobserved) factors might affect $\tilde{\mu}_{t-1}/\tilde{\mu}_t$. Therefore we will also use an alternative specification

$$\frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} = \exp\left(\vartheta_t + \delta\, W_{t-1}/K_{t-1} + c_i\right) \tag{3.13}$$

After inserting (3.13) in the Euler equations, we have to deal with both a multiplicative ($\exp(c_i)$) and an additive individual effect f_i. While this estimation problem can be solved in principle, we will concentrate on the case of the multiplicative effect. Chamberlain (1993) suggested a transformation of the model that yields orthogonality conditions that can be exploited by a GMM estimator. To explain his idea, we write our model succinctly as

$$d_t(y_{it},x_{it};\theta) - r_t(x_{it};\theta)\, C_i = u_{it} \qquad t = 1,\ldots,T \tag{3.14}$$

where y_{it} comprises current endogenous variables (e.g. I_t/K_t) and x_{it} includes predetermined variables. The vector θ comprises the parameters. T is the last year of the sample. Let z_{it} denote the vector of instruments that are orthogonal to the disturbance u_{it}. Now consider the following transformation

$$\rho_t(y_{it},x_{it};\theta) = d_t(y_{it},x_{it};\theta) - r_t(x_{it};\theta)^{-1} r_T(x_{it};\theta)\, d_T(y_{it},x_{it};\theta) \tag{3.15}$$

This is equivalent to

$$\rho_t(y_{it},x_{it};\theta) = u_{it} - r_t(x_{it};\theta)^{-1} r_T(x_{it};\theta)\, u_{iT} \tag{3.16}$$

By the fact that $E(u_{it} z_{it}) = 0$ it follows that $E(\rho_t(y_{it},x_{it};\theta)\, z_{it}) = 0$. However the latter moment condition does not include the unobservable individual effect C_i and therefore can be used for estimation. Notice from (3.17) that the GMM estimator that results, is actually based on quasi-differencing the model. As long as $r_t(x_{it};\theta)$ does not change much over time, this procedure will remove most of the additive individual effect (included in u_{it}) as well.

We conclude this sub-section by giving the estimating equations. We have assumed that the long run revenue is proportional to the sales of the firm, that is $\Pi_t \propto S_t$.

$$(1-\delta^K)\, I_t/K_t = -\, b_2^K \frac{1-\delta^K}{1-\tau} p_t^K + \left(1 + \frac{\rho}{1-\omega}\right) \frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} \Big[b_1^K S_{t-1}/K_{t-1} \tag{3.17a}$$
$$- \tfrac{1}{2} (I_{t-1}/K_{t-1})^2 + I_{t-1}/K_{t-1} + b_3^K (B_{t-1}/K_{t-1})^2 + b_2^K \frac{1}{1-\tau} p_{t-1}^K \Big] + f_i + s_t + w_{it}$$

$$(1-\delta^G)\, R_t/G_t = -\, b_2^G \frac{1-\delta^G}{1-\tau} p_t^G + \left(1 + \frac{\rho}{1-\omega}\right) \frac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} \Big[b_1^G S_{t-1}/G_{t-1} \tag{3.17b}$$
$$- \tfrac{1}{2} (R_{t-1}/G_{t-1})^2 + R_{t-1}/G_{t-1} + b_3^G (B_{t-1}/G_{t-1})^2 + b_2^G \frac{1}{1-\tau} p_{t-1}^G \Big] + f_i + s_t + w_{it}$$

where $\dfrac{\tilde{\mu}_{t-1}}{\tilde{\mu}_t} = \exp\,(\vartheta_t + \delta\, W_{t-1}/K_{t-1} + c_i)$

When the transformation due to Chamberlain is not applied, we replace c_i by $-\,\overline{W_{t-1}/K_{t-1}}$.

The following restrictions between the reduced form parameters and the Euler equation parameters hold

$$b_1^F = -\tilde{\alpha}_F/\phi_F, b_2^F = 1/\phi_F, \text{and } b_3^F = -\zeta_F/\phi_F,\ F = G,K. \tag{3.17c}$$

5.3.2 A Q Model of Investment with Endogenous Financial Regimes

The Q type regression models that will be developed in this sub-section are based on the following relations

$$I_t/A_t = \beta^K_I I_{t-1}/A_{t-1} + \beta^K_Q Q_{t-1} + \beta^K_{INV} INV_{t-1}/A_{t-1} + \beta^K_P p^K_t + \beta^K_B B_{t-1}/A_{t-1} + \beta^K_S S_{t-1}/A_{t-1} + f_i + s_t + w_{it} \quad (3.18a)$$

$$R_t/G_t = \beta^G_I R_{t-1}/G_{t-1} + \beta^G_Q Q_{t-1} + \beta^G_{INV} INV_{t-1}/A_{t-1} + \beta^G_P p^G_t + \beta^G_B B_{t-1}/A_{t-1} + \beta^G_S S_{t-1}/A_{t-1} + f_i + s_t + w_{it} \quad (3.18b)$$

where $Q_t = V_t/A_t$ is "Tobin's Q" , V_t is the market value of the firm net of short term assets, and A_t is "total assets". f_i and s_t are firm and time effects, while w_{it} is an error term. The exact definitions of V_t and A_t are given by

$$V_t = E_t + TB_t - ADJ_t \quad (3.19a)$$

$$A_t = K_t + G_t \text{ (in constant prices of 1987)} \quad (3.19b)$$

where $TB_t = B_t + STDEBT_t$ is total debt
E_t = ValueCOMmonShares + PREFerredSTock is the value of shares [9]
$ADJ_t = CASH_t + RECEIV_t - PAYOTH_t$

The Q models for investment are in reduced form. A lag of investment is added to capture the dynamics of investment. Inventories are included to accommodate different measures of marginal Q that are used in the literature. Debt over assets is included as a measure of agency/bankruptcy costs. Like Gilchrist and Himmelberg (1993), we think that it may be more reasonable to assume that the investment decision is made on the basis of an information set that only includes lagged values of the RHS variables (Q, S etcetera).

Using the switching regression methodology of Lee, Maddala and Trost (1979), we will test for differences in investment behavior across two subsamples (regimes) that correspond to increases in financial working

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[9] The capitals in the names of the variables form the names used in the description of the dataset that we exploited, see Hall (1990a).

capital and decreases ($\Delta(W/A)_t \leq 0$) respectively. A close examination of the Q model suggests that this approach to testing for differences in investment behavior due to financial considerations is more appropriate than that of Fazzari, Hubbard and Petersen, FHP for short, (1988), who classified firms as either liquidity constrained, moderately liquidity constrained, or not liquidity constrained for the whole sample period according to their dividend payout ratio [10]. However, the level of investment is determined by the change in liquidity over time rather than by the average liquidity position of a firm. In the language of our models, the ratios of the current shadow value of funds of a firm to the *future* shadow values of funds of that particular firm, rather than to the shadow values of funds of *other* firms, matter for its investment decision. From the derivation of the Q model [11], we know that the shadow value of capital equals a discounted sum of marginal profits premultiplied by the shadow values of funds μ [12]. The first order condition for investment equates the shadow value of capital λ_t to the marginal cost of investment $\mu_t[(1-\tau)(\partial AC_t/\partial I_t) - \tilde{p}_t^K/\tilde{p}_t]$. Given λ_t, investment is determined by μ_t, $\tilde{p}_t$, $\tilde{p}_t^K$ and K_t [13]. We expect that the value of μ_t in proportion to μ_{t+1}, μ_{t+2},... varies with $(W/A)_t$, just as in the Euler equation model derived in sub-section 5.3.1. Consequently, the coefficient of Q varies across the regimes and is lower when $\Delta(W/A)_t \geq 0$. Since (dis-)investment decisions with respect to working capital are taken frequently, probably several times within a year, the approach followed by FHP seems to be too rough [14].

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[10] Each category contained the same number of firms.

[11] See also chapter 1.

[12] The shadow value of capital $\lambda_t = E_t(1-\tau)\sum_{s=t}^{\infty}\left[\frac{1-\delta}{1+\rho/(1-\omega)}\right]^{s-t}\mu_s p_s \frac{\partial(\Pi_s - AC_s)}{\partial K_s}$.
This follows from solving the Euler equation for the stock of capital forward.

[13] When the future shadow value of funds μ_s is not constant across time, the practice of substituting average Q for average Q is no longer valid. Thus the fluctuations in liquidity are a source of errors in the measurement of marginal Q.

[14] By splitting the sample by the dividend payout ratio, FHP actually divide the sample into a part for which the Q model might be valid, because the shadow value of funds is likely to be constant over time (the dividend paying

The decision to adjust the stock of working capital could be influenced by the same considerations or changes in economic circumstances as the real investment decisions. Therefore we have to consider the possibility of endogenous regime switches, which means that the error term of the model for the indicator of the regime (the sign of the change in working capital) and the error terms of the models for the decision variable of interest (e.g. R&D) that hold under the various regimes are correlated. To complete the system of equations, we have to specify a model for the change in working capital. Being without a real theory about working capital investment, we will specify a reduced form model that includes variables that are likely to be related to the change in working capital

$$\Delta(W/A)_t = \gamma_W \Delta(W/A)_{t-1} + \gamma_Q \Delta Q_{t-1} + \gamma_{INV} \Delta(INV/A)_{t-1} + \gamma_{CSFL} \Delta(CSFL/A)_{t-1} + \gamma_S \Delta(S/A)_{t-1} + u_t \tag{3.20}$$

where $CSFL_t$ denotes cash flows. This model can also be used to predict the regime by replacing $\Delta(W/A)_t$ by a dichotomous variable that equals one when $\Delta(W/A)_t \geq 0$ and zero elsewhere.

The endogenous switching regression model for investment that combines the specifications that hold under the two regimes reads as

$$\begin{aligned} E_t(I_t/A_t) = {} & E_t(I_t/A_t \mid \Delta(W/A)_t < 0)\ \Pr(\Delta(W/A)_t < 0) + \\ & E_t(I_t/A_t \mid \Delta(W/A)_t \geq 0)\ \Pr(\Delta(W/A)_t \geq 0) = \\ & \beta_1' X_t (1-\Phi(\pi' Z_t)) + \beta_2' X_t \Phi(\pi' Z_t) + \phi(\pi' Z_t)(\sigma_{2u} - \sigma_{1u}) \end{aligned} \tag{3.21}$$

where X includes the explanatory variables for investment and Z those for the change in working capital; β and π are the vectors comprising the corresponding coefficients. The subscripts indicate the regime. σ_{ju} denotes the correlation between the error under regime j and the error of the working capital equation. Following common practice, we assumed that the error term of the model for the regime dummy, u_t, follows a standard normal distribution $\Phi(u_t)$. This yields the probit factors $\Phi(\pi' Z_t)$ in equation (3.21). $\phi(u_t)$ is the standard normal density function.

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firms), and two other parts for which the Q model is misspecified, because the equality between marginal Q and average Q (adjusted for the current shadow value of funds) fails to hold. Adding a measure of liquidity to the Q equation does not fix the specification.

Although the framework in (3.21), that combines the specifications for the various regimes, facilitates estimation, it does not allow us to test for endogeneity of the regime switches; only the hypothesis $\sigma_{1u} = \sigma_{2u}$ can be tested.

Also note that even in the absense of correlation between the error terms, that is $\sigma_{1u} = \sigma_{2u} = 0$ (which is known in the literature as the case of exogenous regime switches), the regressors in the switching regression model (3.21) include the probit factors. The difference between the switching model and the naive model that just allows the coefficients to differ across regimes depends on the ability to predict the working capital regime; when one can perfectly discriminate between both regimes, the two models coincide. It should also be borne in mind that there is possibly a great difference between the ability of the econometrician to predict changes in working capital and the extent to which a financial manager can look ahead. Moreover, it is not clear whether a model for working capital observed at the frequency of a year makes sense. For these reasons we will consider both the (endogenous) switching regression model and the simple model that assumes perfect predictability of the regimes in the empirical section.

5.4 Sample Selection and Properties of the Data

The models outlined in section 3 will be estimated and tested with data from the Manufacturing Sector Master File from Hall (1988), which contains a subset of the Compustat data. Since our interest in working capital is mainly based on its relation to ordinary investment and R&D investment in particular, we will limit the sample to firms that have a high R&D intensity. These can be found in the scientific sector, which comprises the chemical industry, SIC 28, the computer industry, SIC 357, the electrical equipment/electronics industry, SIC 36, and the instruments industry, SIC 38. The theories discussed above identified several motives to hold working capital, some of which were connected to the financing of investment. The predictions of most of these theories can be tested best in a period that includes a recession. For instance, the reliquefication theory of Eckstein and Sinai refers to the period at the end of the recession. Therefore our investigations are based on the 1979-1984 period, although the sample we used starts earlier (in 1973) for the construction of lags and instruments.

The empirical investigation starts with an analysis of simple correlations between investment in physical and knowledge capital and financial working capital over time. Table 1 shows the development of the means of several series over time and table 2 displays the simple correlations between important variables both over time and for the whole period 1979-1984. The important facts that emerge from these tables can be summarized as follows.

Ordinary investment decreases from 1979 to 1983 significantly and then one year after the trough of the recession, it rises considerably. R&D expenditure rises over the period, although when 1979 is considered as an exception, it is nearly flat. Sales decrease during the 1980-1982 recession period as expected. While the debt-physical capital ratio declines, working

Table I
Summary Statistics
Means

	1979	1980	1981	1982	1983	1984	St.Dev.
R/G	0.153	0.166	0.175	0.168	0.175	0.174	0.009
I/K	0.151	0.150	0.148	0.133	0.127	0.164	0.010
$(S/K)_{-1}$	3.06	3.12	2.98	2.83	2.69	2.56	0.167
$\Delta S/K^*$	0.227	-0.0732	-0.0162	-0.165	0.0082	0.236	0.040
$(B/K)_{-1}$	0.423	0.410	0.405	0.375	0.356	0.296	0.029
$\Delta B/K^*$	0.171	1.16	-1.56	-0.942	-4.40	1.81	1.48
W/K	0.100	0.106	0.134	0.184	0.247	0.177	0.028
$\Delta W/K^*$	1.30	1.91	3.70	5.17	6.24	-4.66	1.90
$\Delta(W/K)^*$	-1.03	0.592	2.63	4.61	6.06	-4.81	2.03
WK/K	0.797	0.775	0.719	0.711	0.739	0.711	0.058
$\Delta WK/K^*$	3.99	-0.385	-1.52	0.369	3.17	0.861	1.59

* : $(x\ 10^{-2})$

ST.DEV. is average standard deviation of the means, which are computed for each period.

WK= CURRentASSeTs - ShortTermLIABilities

W = CURRentASSeTs - INV - RECEIV - STDEBT = CASH - STDEBT

Table II Simple Correlations

Corr. Period	I/K,DW/K	I/K,DS/K	I/K,DB/K	DW/K,DS/K	DW/K,DB/K	DS/K,DB/K
79	-0.1183	0.1975	0.4505	-0.6394	-0.2401	0.2133
80	-0.2798	0.3464	0.4549	-0.1880	0.0786	0.5197
81	0.0407	0.1502	-0.0481	-0.1857	-0.0653	0.2778
82	-0.1240	0.0328	0.3866	0.1001	-0.1836	0.0700
83	0.1886	0.2764	0.1027	0.0804	-0.1650	0.1932
84	-0.1531	0.3467	0.1621	-0.2765	-0.0868	0.3921
79-84	-0.0744*	0.2333*	0.2583*	-0.2091*	-0.1045*	0.3011*
Corr. Period	**R/G,DW/K**	**R/G,DS/K**	**R/G,DB/G**	**DW/K,DS/G**	**DW/K,DB/G**	**DS/G,DB/G**
79	-0.1351	0.3272	0.2640	-0.2565	-0.0539	0.2870
80	0.0150	0.4200	0.2432	-0.1633	-0.0209	0.6246
81	0.1498	0.1413	-0.0406	-0.0519	-0.0066	0.4211
82	-0.1676	0.0671	0.1726	0.0712	-0.1195	0.1665
83	0.1727	0.2875	-0.0454	0.0019	-0.1274	0.3025
84	-0.0740	0.2372	0.2357	-0.1394	0.0184	0.4123
79-84	0.0024	0.2601*	0.1666*	-0.1000**	-0.0486	0.3739*

For correlations calculated for separate years:
Critical values: 0.2089 (5%), 0.1754 (10%), based on 84 observations.

For correlations calculated over 1979-1984 period (506 obs.):
* : significant at 5% level,
** : significant at 10% level
Tests are heteroskedastic-consistent T-tests based on Seemingly Unrelated Regressions (with identity weighting) which takes the correlations between observations over time into account.

capital (W/K) actually increases during the recession years: the sharpest changes (in opposite directions) of these ratios take place just after the recession in 1983. This is followed by a movement in the opposite direction in 1984. Although this evidence already gives a clue about the possible motives for holding working capital, we will also look at table 2 with the correlations.

Changes in working capital and investment are negatively correlated with the exception of 1983. For R&D the absence of correlation with working capital could not be rejected. From the second column of table 2 we learn that both types of investment are positively correlated with an increase in sales. This could reflect a liquidity or a productivity effect. The fourth column is especially interesting for us as it displays the correlation between changes in working capital and changes in sales. In most years, with the exception of 1982 and (again) 1983, the sign is negative.

All the evidence from table 1 and 2 on the development of investment, R&D, working capital and their correlation patterns over time taken together, the following conclusions seem warranted. First ordinary investment and working capital 'compete' for the available funds. Second working capital is not a temporary depository of funds, used to smooth investment, but seems to be held for precautionary reasons: both in the cross section and in the time dimension working capital and sales are negatively correlated. Third the value of the statistics support the reliquefication theory. In 1983, the first year after the recession, the ratio of working capital to physical capital reaches its maximum, while debt to capital (B/K) drops to a minimum. Furthermore 1983 is the only year in which investment (R&D), the change in sales and the change in working capital are positively correlated. This could be interpreted as follows: the increase in funds is used for investment as usual and to improve the balance sheet, in particular the liquidity of the firm. The more the working capital of the firm rises, the cheaper financing (both internal and external) will be in the near future. This in turn makes investment tomorrow as well as today more likely. In general however (with the exception of the reliquefication period) an increase in working capital is associated with a deterioration of the (financial) condition of the firm.

5.5 Empirical Results

5.5.1 Results obtained for the Q Models

Tables 3a-3c show the regression results for Q models for ordinary investment and R&D. The instruments that were used are listed in appendix 5.A. In table 3a we included sales as a regressor to control for profitability and liquidity. Many empirical studies found that sales has explanatory power beyond Q. Some empirical studies, e.g. Chirinko and Schaller (1993), attribute this to the fact that Q as it is usually measured, namely as the stock market value of the firm over the replacement value of capital, is an imperfect indicator of profitability, which does not fully reflect fundamentals. Table 3c reports the estimates of the switching regression version of the Q model, while table 3d gives various estimation and test results for models of the regime indicator and the 'latent' variable, viz, the change in working capital $\Delta(W/A)$. First we discuss the results for the naive models shown in tables 3a and 3b.

The test results show that in most cases there is no need to include a lag of investment to capture the dynamics. Furthermore most estimates have the right sign or when not are insignificant; we will indicate the exceptions in the discussion of the results. Q does not enter the model of ordinary investment that assumes homogeneity of the parameters significantly, but sales does. However when we dropped sales from the equation, the t-value for Q rose to 2. In the case of R&D, Q performs well as an explanatory variable, while sales has nothing to add or enters with the wrong sign. The preferred measure of Q leaves out the value of the inventories from the numerator, which is plausible since it has not been included in the denominator either. Another interpretation of the results for inventories is provided by Chirinko (1994). He derives a model where Q is related to a weighted sum of various types of investment, like for instance investment in inventories and physical capital as in our model (for ordinary investment). If the gross change in inventories is proportional to its level, which seems plausible, then inventories would enter with a negative sign as they do. Debt over 'total assets', which we measured as the sum of the stocks of physical and knowledge capital, is negatively related to investment, which is in accordance with the presumption that it measures the height of marginal agency costs. The negative relation between debt and investment was also found by Long and Malitz (1985).

Table IIIa

GMM Estimation Results for Q Model

	PHYSICAL CAPITAL		R & D	
	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$
β_I	-0.0950 (0.0764)	0.3417 (0.1890)	0.0333 (0.0837)	0.0768 (0.1703)
β_Q	0.0121 (0.0076)	0.0399 (0.0212)	0.0167 (0.0048)	0.0418 (0.0212)
β_{INV}	-0.0783 (0.0470)	-0.0147 (0.1198)	0.0042 (0.0291)	-0.1753 (0.1076)
β_P	0.0196 (0.0350)	-0.1072 (0.1437)	-0.0107 (0.0178)	-0.0391 (0.0604)
β_B	-0.1032 (0.0281)	-0.2100 (0.0712)	-0.0172 (0.0357)	-0.0071 (0.0588)
β_S	0.0417 (0.0142)	0.0287 (0.0395)	-0.0111 (0.0114)	-0.0290 (0.0391)
$W\beta_I$		-0.3132* (0.1112)		0.2650 (0.1175)
$W\beta_Q$		0.0059 (0.0121)		0.0156 (0.0103)
$W\beta_{INV}$		-0.1344 (0.0747)		0.1665* (0.0754)
$W\beta_P$		0.2965 (0.1267)		-0.0242 (0.0441)
$W\beta_B$		-0.0957 (0.0652)		-0.0518 (0.0534)
$W\beta_S$		0.0754 (0.0214)		-0.0340 (0.0149)
SARGAN (D.F.)	28.911 (29)	19.813 (23)	31.939 (29)	23.545 (23)
DISTANCE (D.F.)		9.757 (6)		4.310 (6)

423 obs., 90 firms, period 1979-1983. Models have been estimated in first differences. HOMOGEN. means parameter homogeneity. W• : coefficients for subsample where $\Delta(W/A) \geq 0$. Time dummies have been included. Heterosked. consistent standard errors are reported below estimates; optimal weighting matrix has been used. Sargan Test and Distance Test ~ χ^2(D.F.).

* (**) : significantly different across regimes at 5 % (10%) level

Table IIIb

GMM Estimation Results for Q Model

	PHYSICAL CAPITAL		R & D	
	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$
β_I	-0.2187 (0.0889)	0.1752 (0.1826)	0.0046 (0.0782)	0.0109 (0.1539)
β_Q	0.0128 (0.0065)	0.0298 (0.0175)	0.0162 (0.0047)	0.0282 (0.0164)
β_{INV}	0.0233 (0.0342)	0.0512 (0.0901)	-0.0124 (0.0247)	-0.1911 (0.0761)
β_P	0.0345 (0.0347)	-0.0793 (0.1349)	-0.0136 (0.0172)	-0.0222 (0.0565)
β_B	-0.1233 (0.0326)	-0.1602 (0.0673)	-0.0225 (0.0349)	-0.0433 (0.0577)
$W\beta_I$		-0.5024* (0.1335)		0.0100 (0.1216)
$W\beta_Q$		0.0066 (0.0117)		0.0114 (0.0092)
$W\beta_{INV}$		0.0074 (0.0608)		0.1057* (0.0639)
$W\beta_P$		0.1793 (0.1076)		-0.0281 (0.0468)
$W\beta_B$		-0.2032 (0.0643)		-0.0630 (0.0511)
SARGAN (D.F.)	29.716 (30)	22.743 (25)	32.658 (30)	27.226 (25)
DISTANCE (D.F.)		7.686 (5)		3.890 (5)

423 obs., 90 firms, period 1979-1983. Models have been estimated in first differences. HOMOGEN. means parameter homogeneity. W• : coefficients for subsample where $\Delta(W/A) \geq 0$. Time dummies have been included. Heterosked. consistent standard errors are reported below estimates; optimal weighting matrix has been used. Sargan Test and Distance Test ~ χ^2(D.F.).

* (**) : significantly different across regimes at 5 % (10%) level

To test for differences in investment behavior between periods in which $\Delta(W/A)$ is positive or negative respectively, we employed a distance test (see for instance Newey and West, 1987). At the 10% significance level, homogeneous behavior could not be rejected both for R&D and for ordinary investment. The estimation results for the subsamples indicate that during periods in which W/A increases, investment is less sensitive to Q as expected, but not significantly so. The significantly positive estimates obtained for the coefficients of inventories and the real investment price in the $\Delta(W/A) > 0$ subsample might be an indication of misspecification or, in the latter case, mismeasurement of the effective capital prices, because we ignored taxes and depreciation allowances.

As we discussed earlier, the endogeneity of the determinant of the regime will result in inconsistent estimates, when the estimation strategy ignores this feature of the model. Therefore we applied the switching regression methodolgy. The estimation results that we obtained for the system that includes the Q models without sales (cf. table 3b) are reported in tables 3c and 3d. First we discuss table 3d, which contains the results obtained for the models for $\Delta(W/A)$ and the corresponding dummy.

Although the explanatory variables are jointly significant according to the value of the likelihood ratio test, our probit model for the sign of $\Delta(W/A)$ is only a slight improvement over a model that only contains a constant from a prediction perspective. This finding should moderate expectations regarding the performance of the switching regression model.

Since we are using panel data, a natural question to ask is whether an individual effect should have been taken into account. However, pooling the data seems justified, as the variables are in first differences. On the other hand, this may cause the error to follow a MA(1) process. Since we actually can observe the 'latent' variable that underlies the regime dummy, we can easily test both hypotheses concerning the nature of the error term after running some simple regressions. We scaled the dependent variable and its lag, so that it looks like a continuous counterpart of the regime dummy variable and the variance of the disturbance is close to one. Note that the 2SLS and OLS estimates are similar to the ML estimates of the probit model, which already suggests that we can treat the error as a white noise process. Next we performed a test due to Godfrey (1978) for the presence of AR(1) behavior (the individual effect) or MA(1) behavior in the error term, which is valid when

the regressors contain a lag of the dependent variable. The absence of serial correlation could not be rejected.

After computing the probability that W/A increases for each observation, we estimated (3.21). Table 3c shows the results. The reported standard errors are lowerbounds for the true standard errors. The error term of model (3.21) is $v_t + (\beta_1 - \beta_2)Z(\hat{\Phi}_t - \Phi_t) + (\sigma_{1u} - \sigma_{2u})(\hat{\phi}_t - \phi_t)$. Our formula for the covariance matrix of the estimators ignores the last two terms [15]. However, joint tests that use the 'wrong' covariance matrix cannot reject the equality of the b's and the σ's across regimes, even though the alternative hypotheses are favored. Therefore we can conclude that our estimates of the standard errors are in most cases not significantly different from the true standard errors.

Most parameter estimates that were significantly different from zero in the naive regressions (table 3b), have become insignificant now. In the case of R&D, the coefficient of Q in the subsample where $\Delta(W/A) > 0$ is higher than in the other subsample, but not significantly. In the case of ordinary investment we find a lower coefficient of Q in the subsample where $\Delta(W/A) > 0$. Summarizing, we can say that the evidence is in agreement with the theory of sub-section 5.3.2. but it is not convincing.

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[15] One can show along the lines of Maddala (1983, appendix to chapter 8) that the difference between the true covariance matrix and the naive covariance matrix, which is based on the assumption that the error term equals v, is a positive definite matrix.

Table IIIc

GMM Estimation Results for Q Model with Endogenous Switching

	PHYSICAL CAPITAL		R & D	
	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$	HOMOGEN.	SPLIT BY $\Delta(W_t/A_t)>0$
β_I	-0.2187 (0.0889)	0.0508 (0.3198)	0.0045 (0.0782)	0.1839 (0.2527)
β_Q	0.0128 (0.0065)	0.0801 (0.0412)	0.0162 (0.0047)	-0.0146 (0.0277)
β_{INV}	0.0233 (0.0342)	-0.1730 (0.2061)	-0.0124 (0.0247)	-0.1804 (0.1467)
β_P	0.0345 (0.0347)	-0.0986 (0.5200)	-0.0136 (0.0172)	-0.4846 (0.2660)
β_B	-0.1233 (0.0326)	-0.3235 (0.2161)	-0.0225 (0.0349)	0.1093 (0.1481)
$W\beta_I$		-0.3916 (0.3401)		-0.2263 (0.1698)
$W\beta_Q$		-0.0488** (0.0325)		0.0339 (0.0223)
$W\beta_{INV}$		0.2134 (0.1773)		0.1199 (0.1242)
$W\beta_P$		0.0768 (0.5186)		0.4239** (0.2648)
$W\beta_B$		0.0951 (0.1706)		-0.1288 (0.1081)
$\sigma_{2u}-\sigma_{1u}$		0.0106 (0.0124)		-0.3E-3 (0.0089)
SARGAN (D.F.)	29.716 (30)	27.431 (24)	32.658 (30)	20.927 (24)
DISTANCE (D.F.)		1.690 (6)		11.740 (6)

423 obs., 90 firms, period 1979-1983.

HOMOGEN. means parameter homogeneity. W* : coefficients for subsample where $\Delta(W/A) \geq 0$. The probits are based on estimation results reported in table IIId. $\sigma_{2u}-\sigma_{1u}$ is the coefficient of $\phi(\hat{\pi}'Z)$, where $\phi(.)$ is the standard normal density function and $\hat{\pi}$ is the vector of estimates of the coefficients of the regressors Z used in the probit model. See also the notes to table IIIb.

Table IIId

Estimation Results for Switching Criterion

	2SLS	OLS		PROBIT ML
γ_C	-0.1486 (0.1007)	-0.1334 (0.0879)	π_C	-0.1924 (0.0953)
γ_W	-0.6199 (0.8569)	-0.1399 (0.0421)	π_W	-0.1141 (0.0459)
γ_I	1.7080 (2.5007)	2.8650 (1.2910)	π_I	2.6846 (1.4768)
γ_{INV}	-3.4538 (3.4635)	-1.5535 (0.6596)	π_{INV}	-1.5577 (0.8649)
γ_S	0.4598 (0.6149)	0.1196 (0.1695)	π_S	0.2830 (0.2268)
γ_{CSFL}	6.6135 (3.6333)	4.9575 (2.1019)	π_{CSFL}	5.9500 (2.3761)
$\bar{R}^2$	0.0194	0.0323	Pseudo R^2	0.0262
LM		1.682	LogL	-340.81
			$-2(\mathrm{Log}\frac{L(\hat{\omega})}{L(\hat{\Omega})})$	18.35
			% pos. obs.	50.69
			% correct pred.	57.82

423 obs., 90 firms, period 1979-1983. Models have been estimated in levels. The dependent (latent) variable is $\Delta(W/K)$. The dependent variable and its lags are normalized by the firm's average of the absolute value of $\Delta(W/K)$. The set of instruments includes most RHS variables and the second lag of $\Delta(W/K)$ instead of the first lag of $\Delta(W/K)$. pos. obs. are observations where $\Delta(W/K) \geq 0$ (regime dummy equals one). Correct pred. means that regime is predicted correctly. The likelihood ratio test statistic for joint significance of slope parameters $\sim \chi^2(5)$. The LM test for the presence of MA(1) or AR(1) errors when the regressors include a lagged dep. var. is from Godfrey (1978): $T\ \hat{u}'\hat{u}_{-1}(\hat{u}_{-1}'\hat{u}_{-1}-\hat{u}_{-1}'Z(Z'Z)^{-1}Z'\hat{u}_{-1})^{-1}\hat{u}'\hat{u}_{-1}/\hat{u}'\hat{u}$. This LM test statistic $\sim \chi(1)$. Heterosked. consistent standard errors are reported below 2SLS/OLS estimates.

5.5.2 Results Obtained for the Euler Equations

Complementary evidence on (financial) working capital as indicator of liquidity and its effects on the investment process is given by table 4, which contains the results for various versions of the Euler equations for ordinary investment and R&D. For the set of instruments used by the GMM estimator we refer again to appendix 5.A. The upper panel of table 4 shows the estimates that are valid under the assumption that no individual effects are present, and the results in the lower panel were obtained after removing the individual effects by first differencing the models. Furthermore the right (even) columns correspond to a specification for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ that is only based on lags of W/K, while the model underlying the left (uneven) columns also included the mean of W/K. The third panel of table 4 shows the estimation results after applying Chamberlain's transformation to get rid of a multiplicative individual effect. All the results in table 4 correspond to the exponential specification for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ (3.14) without separate time effects ($\vartheta_t=\vartheta$). Results based on (3.13) were similar and therefore are not reported. The values for $(1-\delta^G)/(1+\rho/(1-\omega))$ and $(1-\delta^G)/(1+\rho/(1-\omega))$ were fixed at 0.78 and 0.88 respectively.

We will first discuss the estimates computed by using the nontransformed models. The results in columns (2) and (4) — which are only based on levels of W/K — are very similar to results for the models that also include the mean of W/K. In general the estimates of the δ_i's were imprecise. The value of the constant in the exponential model for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ is close to zero, which was our prior, and the estimates for δ_2 have the right sign. Furthermore the results in columns (1) - (4) suggest that the ratio of shadow values depends negatively on the current *change* in W/K. One interpretation is that W_t/K_t (and $\overline{W/K}$) control for an individual effect. Note that the estimates for δ_1 and δ_2 are about the same in the Euler equations for ordinary investment and R&D. This is in agreement with rational behavior which implies that marginal investment projects of different types should earn the same return (after correcting for risk) and are undertaken by using the funds from the same source(s). In other words there is only *one* shadow value of funds which depends on the most profitable investment opportunity that the firm faces. Assuming convexity of the adjustment cost schedule, the estimates of the 'productivity parameter' (b_1) have the wrong sign.

We have performed tests from Keane and Runkle (1992) to ascertain whether individual effects — whether additive or multiplicative — are present. As the RHS variables are endogenous, their presence would destroy the consistency of the estimators used for the upper panel of table 4. The values of various test statistics on the presence of individual effects are shown in table 5. They indicate that it is important to remove additive individual effects in order to obtain consistent estimates of the technology and debt parameters. However no differences are detected between estimates based on the original model in levels and those obtained after applying Chamberlain's transformation. On the other hand the estimates obtained for the first differenced model, FD estimates for short, and Chamberlain's version of the model are different in the case of R&D. Since FD estimates are preferred over the 'levels estimates' and the 'Chamberlain estimates' are not significantly different from the latter, and moreover since the 'Chamberlain estimates' are very imprecise, we will focus in the remainder of this section on the estimates obtained after removing additive individual effects.

The estimate of the intercept δ_0 in the model for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ in the Euler equation for physical capital is significantly less than zero. This implies that the shadow value of funds increased during the recession or in other words that the firm became more liquidity constrained. The estimates of the coefficients of W/K are individually not significantly different from zero [16]. A joint test of significance yielded the same conclusion. Since we suspected that this might be due to multicollinearity we reestimated the model after dropping W_t/K_t but δ_2 (and δ_0) remained insignificant. We also tested whether multiplicative time dummies should be included. The values for this test statistic are reported at the bottom of the second panel in table 4. They suggests that the multiplicative time dummies are missing from the model for R&D. After including the multiplicative time dummies we obtained an estimate for δ_1 (not reported here) that is significantly negative. However our model predicts that δ_2 should enter with a positive sign. In sum the evidence on the effects of working capital on investment provided by the Euler equations is rather weak.

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[16] When we used specification (3.13) for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ we found that δ_2 was significantly positive at the 10% level.

Table IV

GMM Estimation Results for Euler Equations

	Physical Capital		R & D	
		Levels		
	(1)	(2)	(3)	(4)
ϑ	-0.0683 (0.0413)	-0.0528 (0.0386)	-0.0305 (0.0220)	-0.0395 (0.0162)
δ_1	-0.0735 (0.1168)	-0.1217 (0.0999)	-0.0974 (0.0854)	-0.0758 (0.0740)
δ_2	0.1926 (0.1037)	0.1241 (0.0912)	0.0500 (0.0754)	0.0807 (0.0619)
δ_0	-0.1259 (0.1134)		0.0496 (0.0765)	
b_1	0.0034 (0.0020)	0.0037 (0.0020)	0.26E-3 (0.06E-3)	0.24E-3 (0.06E-3)
b_2	0.0210 (0.0417)	0.0145 (0.0321)	0.0032 (0.0063)	0.0037 (0.0055)
b_3	0.0053 (0.0082)	0.0064 (0.0080)	-0.77E-3 (0.27E-3)	-0.69E-3 (0.24E-3)
SARGAN(38)	41.54	40.95	51.72	51.47
		First-Differences		
ϑ	-0.4114 (0.1828)	-0.2990 (0.1354)	-0.0158 (0.0828)	-0.0274 (0.0786)
δ_1	-0.2423 (0.1659)	-0.0800 (0.1053)	-0.1579 (0.1531)	-0.0860 (0.0713)
δ_2	0.0650 (0.1213)	0.1517 (0.0964)	-0.0504 (0.1077)	-0.0216 (0.0633)
δ_0	0.5610 (0.3904)		0.1744 (0.3783)	
b_1	0.0344 (0.0149)	0.0320 (0.0112)	0.07E-3 (0.25E-3)	0.04E-3 (0.23E-3)
b_2	0.1447 (0.1138)	0.1317 (0.1220)	0.0100 (0.0163)	0.0124 (0.0156)
b_3	-0.0957 (0.0408)	-0.1010 (0.0392)	-0.0024 (0.0011)	-0.0025 (0.0011)
SARGAN(38)	43.44	43.48	51.33	51.29
REGR. WALD(6)		68.71		233.92
T.D. WALD(5)		63.16		29.80
DISTANCE(1)	2.73	0.71	1.25	1.05
DISTANCE(5)	4.42	8.08	13.36	8.88

GMM Estimation Results for Euler Equations

		First-Differences continued		
LIQ. WALD(2)	4.27	3.09	1.86	1.54
LIQ+ϑ WALD(3)	6.17	6.03	1.87	1.59
m_1		-4.564		-4.240
m_2		-2.673		-0.887
m_3		2.548		1.125
		Chamberlain's Transformation		
δ_1		-0.4278 (0.8555)		-0.2195 (0.1496)
δ_2		0.6900 (0.4124)		0.0288 (0.1122)
b_1		0.2739 (0.4017)		-0.24E-3 (1.50E-3)
b_2		-0.0166 (0.0872)		0.1353 (0.1205)
b_3		-0.2659 (0.3752)		0.0078 (0.0074)
SARGAN(40)		58.04		59.86
LIQ. WALD(2)		2.802		2.464

421 obs., 90 firms, period: 1980-1984; Optimal HAC weighting matrix used. Additive time dummies have been included, but multiplicative t.d. have not.

$b_1 = -\tilde{\alpha}_F/\phi_F$, $b_2 = 1/\phi_F$, and $b_3 = -\zeta_F/\phi_F$, F = G,K.

$\tilde{\mu}_{t-1}/\tilde{\mu}_t = \exp[\vartheta + \delta_1(W_t/K_t) + \delta_2(W_{t-1}/K_{t-1}) + \delta_0(\overline{W_t/K_t})]$ in left (uneven) col.

$= \exp[\vartheta + \delta_1(W_t/K_t) + \delta_2(W_{t-1}/K_{t-1})]$ in right (even) column.

HAC standard errors below estimates; Wald tests on joint significance of nontrivial regressors and time dummies ~ $\chi^2(.)$; Distance tests for $\delta_1 = 0$, and $\vartheta_t = \vartheta$; m_i i=1,2,3 tests on i-th order autocorrelation ~ N(0,1);

When δ_0 is not restricted to zero, then Sargan test ~ $\chi^2(39)$, Liq. Wald test for $\delta_i = 0 \sim \chi^2(3)$, and Liq.+$\vartheta$ Wald test for $\vartheta = \delta_i = 0 \sim \chi^2(4)$.

Table V

Hausman Tests for Correlated Effects

Models: parameters:	1L vs 1FD	2L vs 2FD	3L vs 3FD	4L vs 4FD
$\vartheta, \delta_1, \delta_2(3)$	4.867 (0.301)	3.659 (0.301)	1.127 (0.890)	1.814 (0.612)
$b_1, b_2, b_3(3)$	8.222 (0.042)	10.666 (0.014)	8.026 (0.046)	9.348 (0.025)
$\vartheta, \ldots, b_3(6)$	10.738 (0.150)	13.106 (0.041)	11.968 (0.102)	13.956 (0.030)
	1L vs Ch.T	1FD vs. Ch.T	3L vs Ch.T	3FD vs Ch.T
$\delta_1, \delta_2(2)$	1.643 (0.440)	1.973 (0.373)	0.903 (0.637)	0.408 (0.816)
$b_1, b_2, b_3(3)$	0.924 (0.820)	2.648 (0.449)	6.015 (0.111)	9.282 (0.026)
$\delta_1, \ldots, b_3(5)$	2.716 (0.744)	4.535 (0.475)	8.820 (0.116)	13.323 (0.021)

Optimal HAC weighting used; p-values below values of test statistics.
The degrees of freedom of the χ^2-distribution of the test statistics shown at the intersection of columns 1 and 3, and rows 1 and 3 is one higher than indicated (4 and 7 respectively).
L is levels version of the model, FD is first differenced version and Ch.T. means that Chamberlain's transformation has been used to get rid of multiplicative individual effect. Number corresponds to column in table IV.

Table VI

ALS Estimates

	(1)	(2)	(3)	(4)
α_F	-0.2377 (0.1768)	-0.2430 (0.2097)	-0.0072 (0.0281)	-0.0031 (0.0193)
ϕ_F	6.9109 (5.4361)	7.5925 (7.0314)	100.00 (163.36)	80.65 (101.30)
ζ_F	0.6614 (0.5252)	0.7670 (0.6379)	0.2408 (0.3707)	0.1981 (0.2318)

421 obs., 90 firms, period: 1980-1984; HAC standard errors below estimates; Exploited restrictions: $b_1^F = -\tilde{\alpha}_F/\phi_F, b_2^F = 1/\phi_F$, and $b_3^F = -\zeta_F/\phi_F$, F = G,K. The estimates of the reduced form par. are shown in columns 2FD and 4FD of table IV.

The estimates of the coefficients of the productivity term have the wrong sign. However, in the case of R&D they are insignificant. Furthermore they are in line with the estimates of the rate of return of R&D found by Hall (1993) for two important industries within the scientific sector, i.e. the chemicals industry and the electrical industry, for the 1971-1980 and 1981-1985 periods (see also table 6 below). The significantly positive estimates for the coefficients of the productivity of physical capital are clearly conflicting with the structural model. Since we are using a instrumental variable approach, the coefficients measure the effect of forecastable sales. Therefore we interpreted this finding as a liquidity effect, rather than a demand shock effect. Another problem with the results for physical capital is that the errors (after first differencing) seem to display third order autocorrelation. This finding casts doubt on the validity of the instruments although the Sargan test does not lead to rejection. The R&D equation passes the specification tests.

According to the results in table 4, debt depresses investment in physical capital and R&D. The estimates of the coefficients of debt are relatively precise. In the case of R&D, we expected that the sign of the coefficient would be determined by the 'intangibility' effect, which says that the larger the share of R&D in total assets, the higher the cost of debt finance. However, the stock of R&D in the denominator of the debt term seems to act as a proxy for total assets, or at least the part that can serve as collateral, which results in the same (negative) sign for the debt term in the R&D equation as has been found in the case of physical capital.

Finally we have calculated the values of the structural parameters that are implied by the estimates in the second panel of table 4. They can be found in table 6. The low precision of the estimates of the adjustment cost parameters spills over into the (high) standard errors of the other estimates.

Although our estimates of the liquidity parameters (δ_j's and ϑ_t's) are rather imprecise, we have also computed some statistics that desribe the development of the cross-sectionsal distribution of $\tilde{\mu}_{t-1}/\bar{\mu}_t$ over time. The means obtained in the case of physical capital, are considerably lower than those in the case of R&D. This could partly reflect differences in the expected rate of return.

Table VII
Cross-Sectional Distribution of $\tilde{\mu}_{t-1}/\tilde{\mu}_t$

Eq. Stat.	1979	1980	1981	1982	1983	1984
R&D Mean	0.845	0.961	0.893	0.703	0.720	0.645
R&D Std.dev.	0.238	0.241	0.214	0.130	0.181	0.151
PHY Mean	0.562	0.639	0.630	0.525	0.516	0.630
PHY Std.dev.	0.0466	0.0617	0.0529	0.0420	0.0468	0.0561

PHY is physical capital; calculations based on estimates of first-differenced versions of models that include $\delta_0,...,\delta_2$ and separate time dummies in submodel for $\tilde{\mu}_{t-1}/\tilde{\mu}_t$ $(\vartheta_{78},...,\vartheta_{84})$.

5.6 Conclusions

The research documented in this chapter has been aimed at measuring the effects of liquidity on investment decisions with respect to both ordinary capital and R&D. To this end we derived versions of the Q model and the Euler equation model, where the perfect capital market assumptions of Modigliani and Miller (1958) are relaxed. The models that we obtained could not be estimated right away as they contained unobservable shadow values of funds. The way we solved this problem distinguishes our research from that of others in this field: exploiting one of the other first order conditions of the value maximization problem of the firm, we established a link between the change in the shadow value of funds and the stock of working capital (relative to the size of the firm). With regard to the sign of this relationship we argued that an increase in working capital may be a measure of precaution (asked for by the bank) and therefore actually reflects a deterioration of the financial position of the firm. When estimating the Q model, we distinguished between two investment regimes defined by the sign of the change in working capital, while we inserted the relationship between the change in the shadow value of funds and working capital in the Euler equation.

The estimation results obtained for the parameters in both models were imprecise in many cases. However some findings do stand out from the tables. First Q significantly explains ordinary investment and R&D, although in the former case it does not capture the marginal profitability of capital

completely since sales enters a regression significantly as well. Second, in both the Q models and the Euler equations, there is a strong negative relationship between the debt term and investment and R&D, which justifies the interpretation that it measures (part of) the marginal (agency) costs of funds. On the other hand, the coefficients of the real cost of capital are poorly estimated, although the sign is correct in most cases. This is perhaps attributable to the fact that the prices in our dataset do not vary across firms but at best across industries defined at the four digit SIC level. Among other things, this means that the prices we used in the analysis do not reflect (differences in) the effective tax rate that firms face. Furthermore the prices will more or less display the same pattern at the industry level, which rises the problem of multicollinearity, given the use of time dummies.

With respect to the main focus of this chapter, measurement of liquidity effects, the evidence does not allow us to draw firm conclusions. Although the estimates of the coefficients of working capital and the differences between the regime specific coefficients of the Q's were in agreement with the predictions from the theory, they were not significant in most cases. Moreover in the Euler equations, the coefficients of the marginal productivity of capital, that is sales over the stock of capital, had the wrong sign. In fact, the Euler equation results resemble those reported in Hall (1991), where the coefficients were allowed to differ across financial regimes defined by the occurrence of dividend payments and the issue of new shares [17]. In that paper, the positive effect of sales on investment and R&D is interpreted as a liquidity effect; the fact that an instrumental variable type estimator has been used, based on instruments lagged two years, makes it unlikely that it is mainly a demand effect, since changes in demand are hardly forecastable two years ahead.

In general, we believe that the results obtained for the Euler equations are more sensitive to timing issues, mismeasurement and misspecification than the results obtained for the Q models, because the Euler equations are first order *difference equations* in de shadow value of capital λ_t, while the Q models are based on the solution of the Euler equation for λ_t, which can be obtained by *adding up* successive Euler equations. Drawing an analogy between the investment models and panel data methods, we know that going from 'levels'

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[17] See the regimes defined on page 12.

(the Q model), to 'first differences' (the Euler equations), aggravates the effects of specification errors.

We close this chapter with some suggestions for obtaining better results for both models. First we could model the change in the shadow value of funds as a joint function of working capital, change in dividend payout, and a dummy variable for the issue of new shares, and perhaps also the variables that were used by Whited (1992) to measure the height of agency costs. Second, since the Euler equations for the various stocks of capital contain the same shadow values of funds, cross equation restrictions can be imposed. Third, one could just concentrate on the Euler equation for physical capital, because that would allow one to use of a much larger sample. Fourth, the strength of the relationship between the change in the shadow value of funds and the change in financial variables, such as dividend payments, depends on the severity of agency problems and problems due to the existence of asymmetric information. In the absence of such problems, this relationship does not even exist. Thus, existing models for the change in the shadow value of funds could be improved by multiplying the proxies for liquidity, e.g. dividend payout ratios, by proxies for agency costs etcetera. Fifth, as mentioned above, the use of firm specific information on prices, which includes effective tax rates, seems desirable. Finally, the switching regression version of the Q model lacks a good equation for the change in working capital. Using quarterly data and adding more lags of the explanatory variables as well as more variables that are informative about the financial position of the firm might help to obtain better results for that part of the model.

Appendix 5.A: sets of instruments

Instruments used for estimation of Q equations:

I_{t-3}/A_{t-3}, W_{t-3}/A_{t-3}, B_{t-3}/A_{t-3}, Q_{t-3}/A_{t-3} , INV_{t-3}/A_{t-3} , $\tilde{p}^K_{t-2}/\tilde{p}_{t-2}$, $\tilde{p}^K_{t-3}/\tilde{p}_{t-3}$, and time dummies
R_{t-3}/G_{t-3}, W_{t-3}/A_{t-3}, B_{t-3}/A_{t-3}, Q_{t-3}/A_{t-3} , INV_{t-3}/A_{t-3} , $\tilde{p}^G_{t-2}/\tilde{p}_{t-2}$, $\tilde{p}^G_{t-3}/\tilde{p}_{t-3}$, and time dummies

Instruments used for estimation of Euler equations:

S_{t-3}/K_{t-3}, I_{t-3}/K_{t-3}, $INTeReST_{t-3}/K_{t-3}$, $DEPREC_{t-3}/K_{t-3}$, $\tilde{p}^K_{t-3}/\tilde{p}_{t-3}$, $\tilde{p}^K_{t-4}/\tilde{p}_{t-4}$, B_{t-3}/K_{t-3}, V_{t-3}/K_{t-3}, W_{t-3}/K_{t-3}, and time dummies.
S_{t-3}/G_{t-3}, R_{t-3}/G_{t-3}, $INTeReST_{t-3}/G_{t-3}$, $DEPREC_{t-3}/G_{t-3}$, $\tilde{p}^G_{t-3}/\tilde{p}_{t-3}$, $\tilde{p}^G_{t-4}/\tilde{p}_{t-4}$, B_{t-3}/G_{t-3}, V_{t-3}/G_{t-3}, W_{t-3}/K_{t-3}, and time dummies.

V_t is defined in (3.19a) as $E_t + TB_t - ADJ_t$ (net value of the firm)

Chapter 6

Summary and Conclusions

In this chapter we summarize the findings of the research reported on in this thesis and conclude with a discussion of some remaining problems/issues.

This thesis investigated the investment decisions concerning physical capital and R&D, and focused on the role of financial considerations in these decisions. For this purpose, we developed new models, that were estimated and tested using American firm data from Compustat. The models were used to examine the importance of the respective mechanism through which the financial factors affect investment, i.e. liquidity constraints, the curve of the supply of funds and the adjustment mechanism. We paid special attention to modeling the dynamical aspects of the capital accumulation process, i.e. the specification of the accumulation constraints, the adjustment cost function and gestation lags or more generally the timing of variables, and to the usual econometric concerns, such as heterogeneity, simultaneity, and measurement errors.

We will first summarize the main findings of each chapter, than compare our findings with those of others and at the end discuss some remaining, unresolved issues.

6.1 The main theoretical and empirical results

Chapter 1 provided a selective survey of the theoretical and empirical literature on investment and financial decisions made by firms. Special attention was paid to the current modeling practice and strategies that researchers have followed to test for the effects of capital market imperfections on investment, although we mentioned the older, classic contributions to the respective parts of the literature too. The arguments and the evidence for the proposition put forward by Schumpeter that R&D intensive firms rely more heavily on internal finance because external finance is more expensive for them ceteris paribus have been summarized. With respect to the empirical literature, we indicated the main findings but also some drawbacks of the approaches that have been used.

In the old literature, it was widely believed that liquidity was an important determinant of investment. However, after the publication of the Modigliani-Miller result in 1958, this belief rapidly vanished. The development of the principal-agent literature and the emergence of the economics of information as well as the unsatisfactory empirical performance of models of investment, both Q models and Euler models, lead to reconsideration of the role of financial factors in the investment decision of the firm. They entered the models by assuming the presence of liquidity constraints or an upward sloping supply of funds curve.

A major problem that researchers in this field face is to discriminate between various interpretations of results, for instance between a liquidity effect or a demand effect interpretation of the effect of sales on investment. Another problem is to find a good indicator of the (change in) liquidity of a firm. In some articles, samples were split by the change in the dividend payout ratio or by the issue of new shares. Since these events take place rather infrequently, they do not perform very well as indicators. To measure the costs of funds, several proxies have been proposed in the literature for the height of agency costs and the severity of the asymmetric information problem. Finally, the fact that outsiders of the firm are less informed than insiders not only affects the costs of funds but also leads to a distinction between the usual Q that is measured using stock market data and the fundamental Q that is based on the insider's (manager's) assessment of the value of the assets within the firm. When the manager follows his own assessment, estimation of the standard Q model is subject to measurement error.

Chapter 2 was devoted to the specification and estimation of Euler equation models for physical (ordinary) capital, knowledge capital and labor that are quite flexible but do not take financial considerations into account yet. The proposed specifications were intended to capture the dynamics, due to net adjustment costs and gestation lags, and interrelations of factor demands and to allow for heterogeneity at the same time. In particular, it allowed for differences in firm size and factor elasticities across firms. The model was based on a generalization of the linear rational expectations model of factor demand discussed in Kollintzas (1985), that allows for gestation lags. The parameters of this model were replaced by functions of firm characteristics, e.g. firm size and factor intensities, which contain hyperparameters.

The set of solutions to the linear rational expectations model with

gestation lags was investigated in chapter 3. By using a convenient decomposition of the matrix lag polynomial of the Euler-Lagrange conditions, that encompasses that of the model without gestation lags, we showed that the extended model admits a unique stable solution. The stability condition derived by Kollintzas turned out to be valid for this more general model as well. Moreover a procedure was given to obtain a closed form solution or at least a semi-closed form solution with restrictions on the AR parameters.

It was not feasible though to obtain a closed form solution of the model of chapter 2, since the parameters were firm specific. Therefore the Euler equations themselves were estimated using a two stage procedure. At the first stage the parameters of the Euler equations were estimated by applying GMM, in the second stage the structural (hyper-)parameters were estimated by applying a minimum distance estimator that exploited the restrictions between the structural parameters and the Euler equation parameters.

In order to obtain as precise estimates as possible, we tried to select relevant moment conditions, that is moment conditions where the instruments are significantly correlated with the RHS variables of the Euler equations. For this purpose, the time series properties of the inputs were investigated. For all series, the stocks of knowledge and physical capital and employment at the firm, we found that a model that describes the series well contains a unit root. The first differenced series follows nearly a random walk in the case of R&D capital, but displays only moderate autocorrelation in the case of the other two series. This finding was a clear warning that we might need many observations in order to obtain significant estimates of the adjustment cost parameters, especially, if we would first difference the Euler equations to control for individual effects. The problem is aggravated by the presence of gestation lags that rules out the use of low lags of some of the inputs and of output as instruments. Therefore, we differenced the instruments instead in the case of R&D capital. In addition to the problem just mentioned, the information on real factor prices that we had was only at the '3.5' digit industry level and was not corrected for the effective tax rate that applies to the firms. For the identification of the parameters, variation across firms due to cost shifters, such as differences in tax rates and the costs of funds, and demand shifters would be instrumental as well.

The estimation and test results that we obtained in chapter 2 can be summarized as follows. First, the net adjustment costs were found to be

strongly separable from the levels of the inputs, which however should not be interpreted as evidence that they are external, because the adjustment cost specification is in relative changes and proportional to the firm size. Second, joint convexity of the net adjustment cost function was rejected. The own adjustment cost parameter of labor on the one hand and those of the stocks of capital on the other hand were of opposite sign. Third, the estimates of the adjustment parameters were on the verge of being significant. The time discount parameter was precisely estimated at a reasonable value.

In chapter 4, we tested the financial accelerator theory. According to this theory, fluctuations in the (agency) costs of funds over the business cycle cause firms to *adjust* their stocks of quasi-fixed inputs *faster* to the optimal levels. The fluctuations in the costs of funds are related to changes in the quality of the balance sheet of a firm over the business cycle. In a downturn, when cash flows drop, smaller and/or bank-dependent firms, either become liquidity constrained or face a big increase in the costs of funds. Therefore these firms reduce (over-)capacity and inventories in order to save working capital. In the upturn, funds are relatively cheap and firms try to adjust their stocks of inputs as much as possible. The influence of the financial factors on the adjustment process is not necessarily symmetric: it is very likely that they are more important during a downturn. The amplitude of the fluctuations of the costs of funds and thereby the speed of adjustment is related to the average height of the agency costs, which is determined by characteristics of the firm, such as its size, leverage and R&D intensity.

The theory was tested in the cases of the accumulation of physical capital and knowledge capital using two types of models: a simple partial adjustment model and an Euler equation model. In the first specification, the adjustment speed was modeled as a function of leverage and firm size, while the sample was split before estimating the second model on the basis of the medium leverage of the firm into two subsamples: one containing the observations of the highly leveraged firms and one containing the observations of the other firms. In the case of the second model, the predicted effects of agency costs on the adjustment behavior of firms were tested by comparing the estimates obtained for the subsamples. Furthermore, in both models we allowed for different behavior across the stages of the business cycle.

The estimates of the parameters in the first model indicated that smaller firms adjust their stocks of physical capital faster than other firms do, and

that the stock of knowledge capital is adjusted more quickly during a recession. The estimation results obtained for the Euler equations confirmed that the adjustment speed of R&D is higher during a downturn, and yielded the same conclusion with respect to the accumulation of ordinary capital.

The symmetric firm size effect in the partial adjustment model of physical capital could well be explained by the notion that smaller firms are more flexible. In sum, the findings indicate that the *speeds of adjustment* of knowledge and physical capital are not constant across the business cycle, but are not affected by financial factors. In other words, the evidence for the financial accelerator theory is rather slim.

Both in chapter 4 and in Chapter 5, we adopted a version of the quadratic adjustment cost function used by Poterba and Summers (1983). This function depends on gross investment, whereas the function in chapter 2 was a net adjustment cost function. Furthermore, we did not allow for gestation lags in chapters 4 and 5 except for the gestation lag of R&D in chapter 4.

Chapter 5 addressed the question to what extent financial constraints and the costs of external finance directly affect the *volume* of investment in ordinary capital and R&D. A theoretical link was established between the change in the tightness of the financial constraints, i.e. change in the shadow value of funds, and the change in working capital over time. This relationship was exploited in the estimation of Euler equation models and Q models of investment that take financial considerations into account.

Estimation results and simple correlations supported the view that working capital is accumulated for precautionary reasons. The change in working capital is negatively correlated with a change in sales. In addition, it is positively correlated with a change in the shadow value of funds, though not significantly so in many cases.

The costs of external funds was measured by leverage. We found that both ordinary investment and R&D expenditures are signifcantly negatively related to debt.

Since the sample used in chapter 5 covered the 1979-1984 period, we were able to test the reliquefication theory. The sample year means showed that an increase in investment at the beginning of an upturn of the economy was preceded by a rise in the stock of working capital and a decrease in leverage. Thus at the end of a recession, firms first improve their balance sheets in order to acquire external funds on more favorable terms, before they start to invest again.

6.2 A Comparison of our Results with the Findings of Others

Focussing on the three channels through which the financial factors affect R&D and investment spending, viz., cost of funds, adjustment speed and liquidity constraints, we can briefly summarize our results as follows. Agency cost problems do reduce investment spending by raising the costs of external funds. Second, they do not influence the speed of adjustment of physical and knowledge capital. Third, we found some weak evidence that liquidity constraints are present and influence investment. After incorporating that mechanism in the model by modeling (the change in) the shadow values of funds, the (wrong) positive sign of the coefficient of sales in the Euler equations for the stocks of capital, that was found before and which could be interpreted as evidence for the presence of liquidity constraints, did not reverse. We have indicated several econometric problems that make it rather difficult to measure the change in the shadow value of liquidity. Bearing these problems in mind and knowing that there is other evidence [1] that indicates that smaller, bank dependent firms face credit rationing or at least receive a smaller part of credit extended during economic downturns than other firms, while presumably they have the same financial needs as these firms, we believe that the third channel does exist.

The negative relation between debt and investment spending has been found by others, namely Long and Malitz (1985), Hall (1991, 1992), and Bond and Meghir (1994).

In the case of labor demand, Sharpe (1994) found that leverage and firm size had an asymmetric effect on the adjustment speed across the business cycle, whereas we did not find any effects in the case of R&D and a symmetric size effect in the case of physical capital. Calomiris et al. (1994) investigated whether and how leverage and size affect the responses of employment, ordinary investment and inventory demand to changes in sales, allowing for different effects across the business cycle. On the one hand, the leverage effects were strongly significant for inventory demand, notably during the recession periods, but on the other hand statistically rather weak in the case of ordinary investment. The differences in these findings may be explained by the fact that adjustment costs are much higher for the stock of

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[1] This evidence is cited in Bernanke, Gertler and Gilchrist (1993).

capital than for inventories. If firms decide to cut spending because of declining cash flows and rising cost of external finance, they are likely to begin by reducing inventories. Most other studies, that tested the financial accelerator theory, compared the behavior of inventories and sales over the business cycle at small and large firms and some of these, e.g. Gertler and Gilchrist (1994), examined whether nonfinancial explanations for the observed differences can be ruled out. These studies presented several pieces of evidence in support of the financial accelerator theory.

With respect to the effects of liquidity constraints on investment decisions, the evidence obtained by most others is just as weak as our results. Bond and Meghir (1994) only obtained results that are consistent with the Euler equation model for a subsample containing data from firms with a high dividend payout ratio. An exception in the literature is Whited (1992), who found evidence for a positive shadow value of debt in part of the sample, which implies the presence of liquidity constraints. When she modeled the shadow value of debt as a function of factors that affect the height of the agency cost of borrowing, e.g. leverage and the interest coverage ratio, the Euler equation for ordinary investment was no longer rejected.

6.3 General Problems

In carrying out this research we encountered several problems that could not be adressed in this thesis because the analysis of these problems was beyond the scope of this thesis or simply because of practical limitations. However we would like to mention some of these problems to put the results in perspective.

A number of problems are related to the use of Generalized Method of Moments estimators. Various papers have examined the small sample properties of the GMM estimators. Tauchen (1986) conducted a simulation study and found that there is a bias/variance trade-off regarding the number of lags used to form the instruments. Kocherlakota (1990) reached the more general conclusion that the use of many instruments could lead to badly biased and inconsistent estimates. This could be explained as follows. As the number of instruments increases the relevance of each additional instrument, as measured by the first-stage (partial) R^2, is likely to become lower. The lower the relevance of instruments, the higher the bias of the estimate. In Euler equation models,

it is often difficult to find enough relevant instruments, as lags of the variables are sometimes the only candidates. With weakly correlated instruments, the inference can also be very misleading. Nelson and Startz (1990) showed that estimates may appear highly significant, when the true population values of the parameters equal zero. However Hall, Rudebusch and Wilcox (1994) warned us that choosing instruments on the basis of relevance criteria, such as partial R^2 or canonical correlations, may actually exacerbate the poor finite-sample properties of estimators. Finally, GMM based Wald tests and the Sargan test for overidentifying moment restrictions are based on the objective function for the GMM estimator. The finite sample distribution of this statistic can differ considerably from its standard asymptotic χ^2 distribution, because the latter does not take the sampling variation of the weighting matrix into account.

A second important problem is the measurement of the stock of knowledge. In theory, it includes all sorts of knowledge that the firm possesses or taps from, e.g. spillovers. In practice, unless one studies these spillovers, the stock of knowledge is usually approximated by a lag function of past own R&D expenditures. However the R&D expenditures measure the *input* to the process of creating knowledge rather than the effective stock that results from R&D efforts. The latter could in principle be measured by patent counts. The relation between the *output* of the knowledge production process and the *input* is subject to some randomness, although in general more R&D efforts are expected to lead to more knowledge. This randomness might lead to measurement errors which, when serially correlated, invalidate lags of the inputs as instruments.

Empirically the weights in the lag polynomial of R&D are hard to identify, because the R&D expenditures series is quite smooth. As a consequence, the effects of the (small) changes in R&D expenditures are swamped by the stochastic 'luck' factor in the production of knowledge. The weights in the lag polynomial of R&D are determined by two kind of factors. First, factors that influence the rate at which the stock of knowledge depreciates and becomes obsolete. Second, factors that determine the time that elapses between R&D investment and the moment at which it becomes productive or starts to contribute to the revenues of the firm. Some have used patent citation data to infer the rate of obsolescence of R&D, e.g. Caballero and Jaffe (1993). The problem of the weights becomes more important if one takes differences when

estimating a model. The identification of the gestation lag is also hampered by the smoothness of the R&D series.

In Chapter 4, we let the accumulation constraint for R&D take the form of a Cobb-Douglas knowledge production function with constant returns to scale. Klette (1994) argued that the properties implied by this function are more consistent with the observed empirical facts, than those implied by the 'perpetual inventory' accumulation rule for R&D. This function can be generalized by allowing for non constant returns to scale and a stochastic 'luck' factor. It is worth noting that the Cobb-Douglas specification for the accumulation of knowledge includes an adjustment cost mechanism that works in a symmetric way. Thus, in contrast to the usual adjustment cost specifications that only result in a reduction of output, this mechanism affects the size of the stock of input, e.g. the stock of knowlege G_t, and eventually output. In the case of R&D, this property seems very realistic.

Finally as stressed before, we need better price information. We made an effort in this thesis to measure changes in/differences in costs of funds, but we could also use data on the effects of tax rules to obtain better factor cost variables.

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List of Symbols

A	production function parameters in Ch. 2; total assets in Ch. 5
A_j	matrices of coefficients in $\Pi(L)$ in Ch. 3
$\overline{A}_{i,j}$	matrices in Ch. 3
B	matrix of adjustment cost parameters in Ch. 2; debt (stock) in Ch. 1,4,5
$B_i, \overline{B}$	matrices in Ch. 3
$\tilde{B}, \tilde{D}$	adj. cost function parameters
C	matrix of parameters in Ch. 3
D	matrix of adjustment cost parameters in Ch. 2; matrix of parameters in Ch. 3; dividends in Ch. 1,5
E	matrix of production function par. in Ch. 2; value of shares in Ch. 5
E_t	conditional expectation operator w.r.t. Ω_t
F	type of input; production function in Ch. 1; number of inputs in Ch. 3
G	R&D stock; matrix of adjustment cost parameters in Ch. 3
H	weekly hours of work in Ch. 2; matrix of adjustment cost par. in Ch. 3
I_t^F	investment in capital of type F
J	$\theta_1 - \theta_F + 1$ (> 0) in Ch. 3
K	physical capital (stock)
K_{ij}	matrices in Ch. 3
L	number of employees in Ch. 2; Lag operator in Ch. 3
M	matrix containing powers in Ch. 3
N	labor
Q	Tobin's Q
R	R&D expenditure
$\hat{R}_i$	matrices in Ch. 3
S	sales; inverse matrix of eigenvectors of $-(C^{-1})D$ in Ch. 3
T	last year of sample
V	value of the firm
V^N	new shares issue
W	matrix in Ch. 3; financial working capital (stock) in Ch. 5
$\underline{W}$	lower bound of financial working capital
$\overline{W}$	matrix in Ch. 3; mean of financial working capital in Ch. 5
X	vector of inputs (stock) in Ch. 2,4; equals $-(C^{-1})D$ in Ch. 3; explanatory variables in Ch. 5
Y	output
Z	matrix in Ch. 3; variable inputs in Ch. 4; explanatory variable in Ch. 5

AC	adjustment cost function
ADJ	Adj. term for short term assets
AGC	agency cost function
ALS	Asymptotic Least Squares
CAPUT	capacity utilization
CASH	cash
CF	cash flow
CFS	Closed Form Solution
CPI	inflation rate
CSFL	real cash flow
ELC	Euler Lagrange Conditions
FEDR	discount rate
GMM	Generalized Method of Moments
INDP	industrial production
INTIR	interest coverage ratio
INV	inventories
LD	Laplace Development
LEV	leverage
LRE	Linear Rational Expectations
ML;MS	lev-$\overline{\text{lev}}$; size-$\overline{\text{size}}$
PAYOT	accounts payable
PDS	Positive Definite Symmetric
PV	present value
RECEIV	account receivable
SIZE	firm size
STDEBT	short term debt
TB	total debt
VC	variable costs
WK	working capital (current assets minus short term liabilities)
P(L)	matrix lag polynomial corresponding to gestation lags
Q(L)	matrix lag polynomial corresponding to adjustment cost function
R(L)	matrix lag polynomial of order g
U(L)	matrix lag polynomial of order τ
V(L)	matrix lag polynomial
a	prod. fct. par. in Ch. 2
b	multiplier in Ch. 1; adj. cost par. in Ch. 2; red. form par. in Ch. 5
$\bar{b}$,$\bar{d}$	adjustment cost parameters

c	constant in knowledge production function
c_F	adjustment cost parameters
c_i, C_i	multiplicative firm effects
d	adjustment cost parameters in Ch. 2; multiplier in Ch. 1,5
d_t	deterministic part of u_t in Ch. 3
$d(.)$	functions of regressors (submodel) in Ch. 5
f	type of input
f_i	additive firm effect
$f(j)$	function with integer argument defined in Ch. 3
g	$J + \tau$ in Ch. 3; growth rate of R&D expenditures in Ch. 4
$g(.)$	technology function
i	firm index
m_i	tests for autocorrelation of order i
$\tilde{p}$	nominal output price
p^F	real price of input F
$\tilde{p}^F; \tilde{p}^Z$	nominal price of input F; nominal prices of variable inputs (vector)
q	personal income tax rate
r	nominal interest rate
s_j^f	gross change in stock of capital of type f (j periods from completion)
s_t	additive time effect
t	time
$\hat{u}$	residual
u_t	error; driving processes in Ch. 3
v	multiplier in Ch. 1,5
w_t	error
y,x	variables (endogenous/predetermined); inputs (stock) in Ch. 3
z	instruments
o	point of approximation
Δ	difference operator
Θ	matrix of parameters of ε_t^0 process in Ch. 3
Λ^+, Λ^-	diagonal matrix containing λ_f^+, λ_f^-
$\Lambda; M$	equals $S^{-1}\Lambda^- S$ in Ch. 3; M equals $I - \Lambda$ in Ch. 3
Ξ	lemon's premium
Π	long run revenue function
$\Pi(L)$	matrix lag polynomial in Ch. 3
Ψ_j^F	investment parameters (type F)
Ω_t	set containing information until time t

α_0 Cobb-Douglas constant
α_F Cobb-Douglas input F elasticities of output
$\tilde{\alpha}_F$ Cobb-Douglas input F elasticities of revenue
β reduced form parameters in Ch. 4,5
γ discount factor; MA parameters in Ch. 2,4; reduced form par. in Ch. 5
δ_{FG} Dirac function
δ reduced form parameters in Ch. 2; structural parameters in Ch. 5
δ^F depreciation rate of capital of type F
ε^D demand shock
ε_t^j revision process
ζ reduced form parameters in Ch. 2,4; agency cost parameters in Ch. 5; diagonal matrix containing eigenvalues of $-(C^{-1})D$ in Ch. 3
η elasticity of scale in Ch. 4; multiplier in Ch. 5
ϑ_F parameters in cost share function in Ch. 2;
ϑ_t multiplicative time effect
θ gestation lag in Ch. 2; constant in Ch. 4; parameter vector in Ch. 5
θ_F gestation lags of quasi-fixed input (of type F)
λ (parameters in) adjustment speed (fct.) in Ch. 4; multiplier in Ch. 1,5
λ_f^+,λ_f^- roots of f-th equation of $\hat{Q}(\lambda) = 0$
μ parameters in partial adj. mechanism in Ch. 4; multiplier in Ch. 1,5
μ_F technological shock (affecting input of type F)
ν elasticity in knowledge production function
ξ^B ξ^W multipliers in Ch. 5
ξ_t a particular function of revision processes in Ch. 3
π inflation rate in Ch. 2; reduced form parameters in Ch. 5
ρ required rate of return
ρ,r functions of regressors (submodels) in Ch. 5
σ_{ij} correlation parameter
τ corporate tax rate; order of MA process in Ch. 3
ϕ_F adjustment cost parameters
$\phi;\Phi$ standard normal density function; standard normal distribution function
χ^2 chi-squared distribution
$m\chi^2$ mixed chi-squares distribution
ψ^D elasticity of demand
ψ_j^F building scheme parameters (type F)
ω capital gains tax rate
$\hat{\omega},\hat{\Omega}$ parameter spaces corresponding to null and alternative hypothesis resp.

Samenvatting - Summary in Dutch

De onderlinge samenhang tussen investeringen in fysiek kapitaal en R&D, en de financieringsbeslissingen van bedrijven.

Doelstelling

Een beroemde stelling in de leer der bedrijfsfinanciering zegt dat onder bepaalde onrealistische aannames financieringsbeslissingen en investeringsbeslissingen van bedrijven onafhankelijk van elkaar kunnen worden genomen. Het nut van deze stelling van Modigliani en Miller (1958) is gelegen in het feit dat zij duidelijk maakt dat in werkelijkheid deze beslissingen niet los van elkaar kunnen worden gezien en vooral ook waarom dat niet kan.
In dit proefschrift wordt onderzocht hoe en in welke mate het financieringsprobleem van invloed is op de omvang en de 'timing' van de investeringen in fysiek kapitaal en onderzoek en ontwikkeling (R&D). Wij onderscheiden daarbij drie mechanismen waardoor de financiële omstandigheden van een bedrijf zijn investeringen mogelijk beïnvloeden. Allereerst veronderstellen wij een (positief) verband tussen de verhouding tussen de schulden en het onderpand van het bedrijf enerzijds en de kosten van externe financiering anderzijds. Als tweede mechanisme dat het niveau van de investeringen kan beïnvloeden beschouwen wij financieringsrestricties, zoals de liquiditeitsrestricties, een bovengrens op schuldfinanciering en/of een ondergrens voor (financieel) werkkapitaal. Tenslotte is het denkbaar dat financiële factoren via het aanpassingsmechanisme niet zozeer het volume van de investeringen bepalen als wel het moment waarop zij plaatsvinden binnen de conjunctuurcyclus.
Alvorens de financieringsaspecten in de modellering van bedrijfsinvesteringen te betrekken, wordt de dynamiek van deze processen onderzocht. Hierbij worden twee bronnen van dynamiek beschouwd: aanpassingskosten en bouwtijden. In een afzonderlijk theoretisch hoofdstuk worden de eigenschappen van de oplossing van een lineair rationele verwachtingen model met aanpassingskosten en bouwtijden bestudeerd.
Door het hele proefschrift heen wordt aandacht geschonken aan econometrische problemen zoals de enorme heterogeniteit in de gegevens, meetfouten, simultaniteit en timing van variabelen en de formulering van momentencondities

voor de constructie van schatters.
Hieronder volgen de samenvattingen van de afzonderlijke hoofdstukken.

In *Hoofstuk 1* wordt een literatuuroverzicht gegeven van de neoklassieke investeringsmodellen en de theorieën over de financieringsbeslissingen van bedrijven. Vervolgens wordt de empirische literatuur over de gevolgen van onvolkomenheden in het functioneren van de kapitaalmarkten voor investeringen in fysiek kapitaal en R&D besproken. Daarbij wordt ook aandacht besteed aan de problemen die men tegenkomt bij dit onderzoeksterrein en de tekortkomingen van de strategieën die in het verleden gebruikt zijn om de effecten te onderzoeken.
Hoofdstuk 2 is gewijd aan de specificatie en schatting van Euler vergelijkingen voor de vraag naar kapitaal, R&D en arbeid. De modellen zijn flexibel gespecificeerd, zodat ze de dynamiek van de produktiefactoren, die voortvloeit uit aanpassingskosten en bouwtijd, en hun wederzijdse beïnvloeding als ook de heterogeniteit van bedrijven, waar het hun grootte en factorintensiteiten betreft, zo goed mogelijk kunnen beschrijven: de modellen zijn een variant op het lineaire 'rationele verwachtingen' model van Kollintzas (1985). In deze modellen worden de financieringsaspecten van de factorvraag echter buiten beschouwing gelaten.
Omdat het factorvraag-model geen zogenaamde 'gesloten vorm' oplossing heeft, is het volgens de methode van gegeneraliseerde momenten (GMM) geschat. Om betrekkelijk precieze schattingen te verkrijgen, vereist deze schattingsmethode de specificatie van 'relevante' momentencondities. Hiertoe werden de tijdreekseigenschappen van de produktiefactoren onderzocht. De reeksen van alle drie de produktiefactoren blijken minimaal één eenheidswortel te hebben en R&D kapitaal blijkt er zelfs twee te hebben. Daarom was het wenselijk het model voor R&D, dat heterogeniteit in het intercept toelaat, in niveaus te schatten met instrumenten in eerste verschillen. Afgezien van de eenheidswortels is de autocorrelatie die de reeksen van de produktiefactoren vertonen laag. Daarom en ook vanwege de bouwtijden is een groot aantal waarnemingen nodig om de parameters enigermate precies te kunnen schatten.
De schattings- en toetsresultaten van hoofstuk 2 laten zich als volgt samenvatten. Op de eerste plaats zijn de *relatieve* aanpassingskosten sterk separabel van de niveaus van de produktiefactoren, wat overigens niet betekent dat zij extern zijn. Ten tweede wordt convexiteit van de aanpassingskosten

verworpen. In de derde plaats vinden we dat de parameterschattingen maar net significant zijn maar ook dat de schatter van de tijdsvoorkeurparameter een zeer redelijke waarde heeft.

In *hoofdstuk 3* worden de eigenschappen van de oplossingen van een lineair rationele verwachtingen model met zowel aanpassingskosten als bouwtijden bestudeerd. Met behulp van een handige decompositie van het matrix vertragingspolynoom van de Euler-Lagrange voorwaarden, die dat van het model zonder bouwtijden omvat, is aangetoond dat het model een unieke, stabiele oplossing heeft. De stabiliteitsvoorwaarde die door Kollintzas (1985) was afgeleid is in het uitgebreide model nog steeds van toepassing. Er wordt ook een procedure aangegeven om een 'zoveel als mogelijk gesloten' oplossing van het model af te leiden. Voor het autoregressieve gedeelte van de formulering van de oplossing wordt in ieder geval een expliciete formule afgeleid.

In *hoofdstuk 4* wordt de financiële accelerator theorie aan een toets onderworpen. Volgens deze theorie verhogen de fluctuaties in de 'agency' kosten van externe financiering, die zich binnen een conjunctuurcyclus voordoen, de snelheden waarmee de hoeveelheden van de quasi-vaste produktie-middelen worden aangepast in de richting van de optimale hoeveelheden. De amplitude van de fluctuaties in de 'agency' kosten wordt in verband gebracht met enige factoren die eveneens het gemiddelde van die kosten beïnvloeden: de bedrijfsgrootte, de verhouding tussen de schulden en de bezittingen (de 'leverage') èn de R&D-intensiteit van het bedrijf.

De financiële accelerator theorie wordt getoetst met behulp van twee soorten modellen: een eenvoudig partiële aanpassingen model, waarbij de aanpassingssnelheid afhangt van bovengenoemde determinanten van de 'agency' kosten, èn een structureel 'Euler vergelijking' model dat voor verschillende 'leverage' categorieën binnen de steekproef wordt geschat, waarna de schattingen worden vergeleken. Voor beide soorten modellen gaan we na of er sprake is van asymmetrie tussen de effecten op het aanpassingsgedrag in de herstelfase en in de recessiefase van de conjunctuurcyclus respectievelijk.

Allereerst blijkt uit de statistische analyses dat de aanpassingssnelheid van fysiek kapitaal hoger is naarmate een bedrijf kleiner is maar dat zij niet gevoelig is voor de verhouding tussen de schulden en de bezittingen van het bedrijf noch voor zijn R&D-intensiteit. Op de tweede plaats vinden we dat zowel het niveau van de R&D investeringen als de aanpassingssnelheid van R&D hoger zijn bij bedrijven die kleiner zijn dan wel een lagere 'leverage'

hebben, althans wanneer we constantheid van de coefficienten veronderstellen. Doen we dit niet, dan blijkt er nog slechts sprake te zijn van een hogere aanpassingssnelheid van R&D tijdens de recessie, die niet samenhangt met de bedrijfsgrootte noch met de 'leverage' van het bedrijf. Ook voor fysiek kapitaal vinden we een hogere gemiddelde aanpassingssnelheid in de recessie, dus ongeacht de karakteristieken van het bedrijf. De verklaring van het (symmetrische) negatieve effect van de bedrijfsgrootte op de aanpassingssnelheid van fysiek kapitaal zou gelegen kunnen zijn in het feit dat kleinere bedrijven doorgaans flexibeler zijn in technisch en organisatorisch opzicht.

In *hoofdstuk 5* worden Q modellen en Euler vergelijkingen voor investeringen geschat, die rekening houden met liquiditeitsrestricties via de schaduwprijzen van financieringsmiddelen en ook met een elastisch aanbod van externe middelen. De Euler vergelijkingen corresponderen met het waarde maximalisatie probleem van een bedrijf met een Cobb-Douglas technologie met kwadratische bruto aanpassingskosten. Omdat de schaduwprijzen niet waarneembaar zijn, zijn deze modellen niet zonder meer geschikt voor een empirische analyse. Door een eerste orde voorwaarde voor een andere beslissingsvariabele in de doelstellingsfunctie van het bedrijf, namelijk voor werkkapitaal, af te leiden en een veronderstelling te maken over het gedrag van de schaduwprijs van deze variabele, zijn wij in staat een verband te leggen tussen de schaduwprijzen van de financieringsmiddelen en het werkkapitaal van een bedrijf, dat we wel kunnen waarnemen. Werkkapitaal lijkt een geschiktere variabele om veranderingen in de liquiditeit van bedrijven te meten dan sommige andere variabelen, die in het verleden gebruikt zijn, zoals dividenden en aandelen-emissies, omdat deze variabele beweeglijker en ook continu is. Wij geven argumenten waarom een stijging van werkkapitaal, gedefinieerd als het verschil tussen cash en de korte termijn schulden, geïnterpreteerd kan worden als een verslechtering van de liquiditeitspositie van een bedrijf.

Onze variant van het Q model met liquiditeitsrestricties komt tegemoet aan de kritiek op benaderingen die in het verleden gevolgd zijn. Ten eerste laten wij de coëfficiënt van Q variëren met de verandering in de liquiditeitspositie van het bedrijf. Daarmee wordt ook de ad hoc toevoeging van een term die de verandering van de liquiditeitspositie zou moeten weergeven, zoals cash flow, overbodig. Ten tweede wordt er rekening gehouden met de endogeniteit van de veranderingen in de liquiditeitspositie van een

bedrijf door de Q vergelijking te schatten als een model met endogene regimes.

In beide modellen worden de kosten van externe financiering gemodelleerd als functie van de verhouding tussen schuld en de kapitaalvoorraad.

De resultaten die zijn verkregen voor de Euler vergelijkingen voor fysiek kapitaal en R&D zijn net zo zwak als die in andere studies, ondanks de nieuwe modelleerstrategie. Hoewel de schattingen van de coëfficiënten van werkkapitaal wel de juiste tekens hebben, zijn zij vaak niet significant. Ook de coëfficiënten van de productiviteitstermen hebben nog steeds het verkeerde teken. Daarom kunnen zij misschien beter geïnterpreteerd worden als variabelen die de verandering in de liquiditeit weergeven. Zowel in de Euler vergelijkingen als in de Q modellen zijn investeringen en de (vertraagde) waarde van schuld negatief gecorreleerd.

De negatieve correlatie tussen de veranderingen in de omzet en het werkkapitaal van een bedrijf en de positieve correlatie van werkkapitaal met de schaduwprijs van financieringsmiddelen suggereren dat werkkapitaal mede uit voorzorg wordt aangehouden. Verder ondersteunen de patronen in de jaargemiddeldes van werkkapitaal en 'leverage' de 'reliqueficatie'-theorie: aan het eind van de recessie en in het begin van een periode van herstel van de economie verbeteren bedrijven eerst hun financiële positie door een deel van hun schuld af te lossen en hun werkkapitaal te vergroten alvorens weer te investeren.

Hoofdstuk 6 vergelijkt tenslotte de bevindingen omtrent de invloed van de verschillende financiële mechanismes op de investeringen, d.w.z. de invloed van de liquiditeitsrestricties, de financiële accelerator en de elastische aanbodcurve van externe fiancieringsmiddelen op de investeringen, met die van andere studies en sluit af met de bespreking van een aantal methodologische problemen bij het schatten en toetsen van de modellen en het meten van de R&D kapitaalvoorraad.

De belangrijkste indruk die naar voren komt bij de empirische investeringsstudies in dit proefschrift maar ook bij die van anderen is dat ondanks de grote hoeveelheid micro-data de schattingsresultaten vaak maar net significant zijn. Zoals elders in dit proefschrift al is opgemerkt, zijn daar vele verschillende oorzaken voor aan te geven, zoals bijvoorbeeld de enorme heterogeniteit van bedrijven, meetfouten of gewoon gebrek aan bepaalde informatie. Door modellen flexibeler te specificeren en/of te transformeren,

kan men het risico dat een geschat model een sterk vertekend beeld geeft verkleinen. Dit gaat echter ten koste van informatie en dus ten koste van de precisie van de schattingen. Om dit te voorkomen is het wenselijk om de verschillen tussen de bedrijven beter te modelleren. Daarvoor hebben wij goede theorieën en ook betere data nodig.

De rol die de beschikbaarheid en de kosten van financiële middelen spelen bij investeringsbeslissingen kan niet genegeerd worden. Zij vormen een belangrijke bron van verschillen tussen de condities waaronder bedrijven opereren.

Curriculum Vitae

Hugo Kruiniger werd op 5 mei 1967 in Gouda geboren. In 1985 slaagde hij voor het Gymnasium β examen aan het Jeanne d'Arc College te Maastricht. Van 1985 tot 1991 studeerde hij algemene econometrie aan de Erasmus Universiteit in Rotterdam. Gedurende de laatste fase van zijn studie, was hij student-assistent bij de vakgroep Wiskundige Economie aan deze universiteit. Na het behalen van het doctoraaldiploma, trad hij in februari 1991 in dienst als assistent-in-opleiding bij de vakgroep Kwantitatieve Economie aan de Economische Faculteit van de Rijksuniversiteit Limburg. In mei 1992 werd hij onderzoeker-in-opleiding in dienst van NWO. Met een Fulbright beurs verbleef de auteur van november 1993 tot en met maart 1994 aan het National Bureau of Economic Research en de Faculty of Economics van Harvard University. Vanaf Januari 1996 verblijft hij als post-doctoral fellow vijf maanden aan het CREST/INSEE in Parijs.

Hugo Kruiniger (born May 5th 1967, in Gouda) studied econometrics at Erasmus University Rotterdam from 1985 until 1991. After he graduated in January 1991, he became a Ph. D. student at the Department of Quantitative Economics of the University of Limburg. Since May 1992 his research was sponsored by the Netherlands Organization for the Advancement of Pure Research (NWO). In the fall of 1993 he received a Fulbright scholarship from N.A.C.E.E. . He stayed for five months at the National Bureau of Economic Research and the Faculty of Economics of Harvard University both in Cambridge, Massachusetts. At present he is a reasearch fellow at the Centre de Recherche en Economie et Statistique (CREST/INSEE) in Paris.