MICRO-ECONOMETRIC MODELS FOR ANALYSING CAPITAL ADJUSTMENT ON DUTCH PIG FARMS

Promotor:	prof. dr. ir. A.J. Oskam Hoogleraar Agrarische Economie en Plattelandsbeleid
Co-promotoren:	dr. ir. A.G.J.M. Oude Lansink Universitair hoofddocent bij de leerstoelgroep Agrarische Bedrijfseconomie
	dr. ir. J.H.M. Peerlings Universitair docent bij de leerstoelgroep Agrarische Economie en Plattelandsbeleid
Promotiecommissie:	prof. dr. H. Folmer (Wageningen Universiteit) prof. dr. A.R. Hall (North Carolina State University, USA) prof. dr. G. Pfann (Universiteit Maastricht) prof. dr. A. van Soest (Katholieke Universiteit Brabant) prof. dr. S.E. Stefanou (Pennsylvania State University, USA)

Cornelis Gardebroek

MICRO-ECONOMETRIC MODELS FOR ANALYSING CAPITAL ADJUSTMENT ON DUTCH PIG FARMS

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
prof. dr. ir. L. Speelman,
in het openbaar te verdedigen
op vrijdag 22 juni 2001
des namiddags te 16.00 uur in de Aula

Ontwerp illustratie omslag: Marieke ten Berge
Druk: Grafisch Bedrijf Ponsen & Looijen bv, Wageningen

Gardebroek, C.

Micro-econometric models for analysing capital adjustment on Dutch pig farms
/C. Gardebroek
PhD-thesis Wageningen University. – With ref. – With summary in English and Dutch
ISBN 90-5808-447-7

Subject headings: Micro-econometrics, capital adjustment, pig farming

Voor mijn vader

(1944-1991)

VOORWOORD

Dit proefschrift gaat over investeren. Het aardige is dat het schrijven van dit proefschrift, en alles wat daarmee samenhangt, zelf ook een investering is en wel in mijn ‘human capital’. Dit promotieonderzoek is een investering over meerdere jaren waarbij bij aanvang, ongeveer vierenhalf jaar geleden, de uitkomst nog onzeker was. De drempel om tot deze investering over te gaan was destijds niet hoog. Mijn enthousiasme voor het wetenschappelijk onderzoek was al ontstaan in de eindfase van mijn reguliere studie aan de toenmalige Landbouwuniversiteit Wageningen.

Een investering als deze hoef je gelukkig niet alleen te doen. Allereerst wil ik mijn begeleiders prof. dr. ir. Arie Oskam, dr. ir. Alfons Oude Lansink en dr. ir. Jack Peerlings bedanken voor hun deskundige inbreng. Of het nu het samen schrijven van artikelen, het becommentariëren van geschreven stukken of het adviseren m.b.t. de voortgang van het onderzoek betrof, de samenwerking was altijd plezierig en stimulerend. Wilbert Houweling stond altijd klaar om te helpen op het gebied van computers en software. Rien Komen gaf gestalte aan het gezegde dat een goede buur beter is dan een verre vriend. Onze vele koffierondjes kenden een gezonde mix van diepgang en humor. Mijn overige collega’s en de vele bezoekers van de leerstoelgroep Agrarische Economie en Plattelandsbeleid wil ik bedanken voor de prettige en professionele werksfeer. Dat die sfeer goed is blijkt wel daaruit dat veel mensen na hun promotie (tijdelijk) bij de groep blijven werken.

Het Landbouw-Economisch Instituut (LEI) in Den Haag bedank ik voor het beschikbaar stellen van de data die gebruikt zijn in dit proefschrift. Met name Bernard Douma heeft meerdere malen een toelichting gegeven op bepaalde gegevens. Verder wil ik de stichting LEB fonds uit Wageningen bedanken voor de verstrekte beurzen die het mogelijk maakten internationale congressen te bezoeken om mijn werk te presenteren. Het NWO-SIR fonds maakte het mogelijk een kort werkbezoek te brengen aan de Pennsylvania State University.

Investeren gaat altijd gepaard met onzekerheid. Waar ik echter in ieder geval zeker van kon zijn de afgelopen jaren was de steun en interesse van Jenita. En wat Reinard en Eline betreft, jullie komst was een welkome afwisseling!

Koos Gardebroek

Wageningen, april 2001

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background

Farmers operate their business in a dynamic environment. Fluctuating prices, increasing consumer demands for product quality (e.g. with respect to environmental friendly production methods, animal welfare and food safety), technological change and evolving agricultural and environmental policies frequently require adjustment of production and input levels on individual farms. Quantities of variable production factors like animal feed can usually be adjusted easily together with changing production levels. Quantities of labour, capital and land however, are less easy to adjust. Instantaneous adjustment may be impossible or imply (high) costs of adjustment. In the long run, quantities of these quasi-fixed factors can be adjusted at lower costs of adjustment.

The Dutch pig sector is an interesting case for studying adjustment of quasi-fixed factors. With the total number of pigs increasing from 10.1 million in 1980 to 13.6 million in 1999 and the number of farms with pigs decreasing from 44 thousand to 16 thousand in the same period (LEI/Statistics Netherlands, 2000: 101), it is clear that the average size of Dutch pig farms has increased rapidly the last two decades. This increase in average size, accompanied by an ongoing specialisation, implied considerable adjustments for individual farms. However, the increasing scale of production also led to growing pressure on the environment. Starting in the mid-eighties, the Dutch government implemented a number of policy measures to stop the growth of pig production (for an overview see LEI, 2000: 88). Restrictions on expansion were set by means of building and environmental licenses followed by a system of manure production rights. Expansion of the farm business was only possible by buying additional manure production rights or land. With the pig sector restructuring law introduced in 1998, the system of manure production rights was replaced by a system of pig rights, where the quota level was set at 90% of the number of pigs held in 1996 (LNV, 1998). Moreover, since 1998 farmers are obliged to register in- and outflows of minerals (phosphate and nitrogen) on their farm (LNV, 2000). The inflow of minerals is mainly based on the amount of purchased pig feed. Pig supply and transported or processed manure account for mineral outflows. Based on these mineral flows and the amount of farmland, mineral surpluses are calculated and taxed. This package of legislation has had a significant impact on pig production, providing another reason to study adjustment behaviour on Dutch pig farms. Furthermore, in response to growing consumer concerns about animal welfare, the government and the food processing industry imposed a number of regulations. Examples are the use of straw beds in pig places and the grouping of sows. Moreover, in deciding on when and how much to adjust their stock of quasi-fixed factors pig farmers are faced with fluctuating prices, underlining the dynamic environment in which pig farmers operate.

Understanding the process of adjustment of quasi-fixed factors is important for a number of reasons. First, it shows how farmers reorganise their production in the long run as a reaction to changes in the economic environment, e.g. a decrease in output prices. Second, understanding adjustment of quasi-fixed factors may explain farmers' entry and exit decisions. Third, knowledge about long run adjustment processes at the farm level can be used in economic models to simulate long-term effects of agricultural and environmental policies on individual farms. Policy makers are often interested in these long-term effects (Meester, 1995).

In order to study the economic aspects of factor adjustment at the farm level, a theoretical framework is required that explicitly takes individual farmers' behaviour into account. Pig farms in the Netherlands are mainly small-scale farms operated by the farmer and his family. This implies that farmers are price takers in the markets of inputs and outputs. Neo-classical production theory is an appropriate framework for describing economic behaviour of individual pig farmers. This theory states that farmers optimise an objective function (profit function, cost function) subject to a set of constraints. Optimal behaviour is then characterised by a set of marginality conditions (for an overview see Beattie and Taylor, 1985; Varian, 1992).

In this thesis the main focus is on modelling adjustment of capital at individual Dutch pig farms, taking farm-specific characteristics into account. However, stated in these terms the topic is rather broadly defined and contains a variety of aspects that can be studied. Therefore, in this thesis a selection of topics is made. Given that farm-specific characteristics are taken into account throughout this thesis, the first topic is on investigating the nature of the unobserved farm-specific characteristics, in which management is an important element. The second topic is on the utilisation of capital when the quantities cannot be adjusted in the short-run. The third topic is long-run adjustment of capital and the fourth topic is the impact of government policies on capital investment. In the remainder of this section the choice of these topics is motivated more specifically.

Managerial ability and panel data

Individual qualities of a farm operator are assumed to be an important determinant in pig production. Technical skills and skills in organising the production process, which are both considered to be elements of an aggregate management variable, not only have a direct impact on production and profits, but also interact with other production factors. However, despite its importance still little is known about this management variable (Nuthall, 2001). An interesting question is for example how it relates to the available quantities of quasi-fixed factors on individual farms. A major problem however that prevents a thorough investigation of this management variable is that it is unobserved.

The availability of balanced and unbalanced panel data sets allows for empirical analyses at the individual farm level. Moreover, there is a growing body of literature on econometric panel data methods focusing on how to account for unobserved individual characteristics. Baltagi (1995) gives an overview of panel data econometrics. Applications in the agricultural economics literature are found in e.g. Thijssen (1992), Hallam and Machado (1996) or Carpentier and Weaver (1997). Depending on whether these unobserved individual effects are assumed to be fixed parameters or random variables, a fixed effects respectively a random effects approach is used.

Micro-economic models of production often imply estimation of a system of output supply and input demand functions. Following Mundlak (1961), farm-specific effects in such models represent the unobserved management variable. Its relation to other production factors (e.g. capital) can be investigated using the panel data estimator proposed by Hausman and Taylor (1981). Their approach allows for performing tests on correlation of different sets of explanatory variables with the farm-specific effects, thereby yielding insight in the unobserved management variable and its relation to quasi-fixed factors in pig production. Furthermore, the Hausman-Taylor estimator combines a number of desirable properties of the fixed effects and random effects estimators. It gives consistent estimates and it allows for estimating parameters corresponding with time-invariant but farm-specific variables such as region, education level, sex and presence of successor.

The relation between the unobserved management variable and quasi-fixed factors in production has not been investigated thus far. Moreover, the Hausman-Taylor estimator has not yet been developed for estimating a system of equations with unbalanced panel data.

Factor utilisation under supply quota

Although farmers cannot adjust the quantities of the quasi-fixed factors in the short run, sometimes they utilise only part of the available quantities. For example when supply quotas are introduced and the restricted quota quantities are well below the optimal production levels, farmers may be forced to reduce the utilisation of the available quasi-fixed factors in the short run. Specialised Dutch pig farmers experienced such a situation when the pig sector restructuring law was introduced in 1998. Although there were some exceptions, in general they were only allowed to keep 90% of the number of pigs kept in 1996. In the short-run, this led to empty places in pig units and reduced utilisation of available labour. Reduced utilisation of quasi-fixed factors has an effect on the shadow price of production and the price that farmers can pay for additional supply quota in the short-run. In case of tradable supply quotas, this is relevant for pig farmers who buy or sell additional pig supply quotas. If quotas are not tradable, it is relevant for the government who buys out individual pig farmers, since it needs information on farmers' valuation of supply quotas. However, the short-run effect of output rationing on factor utilisation has been ignored in previous studies dealing with supply quotas (see e.g. Babcock and Foster, 1992; Rucker et al., 1995; Boots et al., 1997).

Capital adjustment patterns on Dutch pig farms

In order to explain capital adjustment in the long run, a number of theories exist. Already in the 1950's two theories explaining adjustment of quasi-fixed factors were developed, i.e. Cochrane's (1955) treadmill theory and Johnson's fixed asset theory (1956). Starting from the 1980's many agricultural economic studies have applied the adjustment cost framework in order to explain adjustment of quasi-fixed factors (see e.g. Vasavada and Chambers, 1986; Howard and Shumway, 1988; Thijssen, 1996). In these studies it is assumed that a farm incurs a cost in adjusting its stock of quasi-fixed factors, preventing immediate adjustment of the quasi-fixed factors. Examples of these costs are reductions in output due to the restructuring of the production process, administrative costs, search costs, etc. A popular specification for the adjustment cost function is the symmetric quadratic, implying strictly convex adjustment costs over the whole range of adjustment. Convex adjustment costs imply that it is cheaper to spread investments over time than to adjust instantaneously. However, the symmetric quadratic specification has the drawback that it cannot explain zero investments adequately, whereas zero investments are frequently observed in farm level data. Another drawback of the symmetric quadratic adjustment cost specification is that it imposes adjustment costs of investment and dis-investment to be symmetric. However, a priori there is no reason to assume that acquiring capital involves the same adjustment cost as removing it.

In order to address these shortcomings, two empirical studies that combine fixed asset theory and adjustment cost theory have appeared recently. Oude Lansink and Stefanou (1997) estimated a dynamic dual threshold model of investment that allows for asymmetric adjustment and explicitly accounts for zero investments. Pietola and Myers (2000) estimated an extended dynamic dual model including uncertainty. Both studies used farm-level data to estimate the generalised adjustment cost function model.

However, what has not been taken into account in these studies is that farms may differ in the adjustment costs they face for a given investment. The difference between the unit purchase and selling price is not necessarily the same for all farms. Furthermore, reductions in production (internal adjustment costs), costs of acquiring building and environmental licenses necessary for investment, administrative costs and search costs (external adjustment costs) are expected to differ by farm for a given investment. Moreover, Oude Lansink and Stefanou (1997) and Pietola and Myers (2000) use the dual approach in modelling dynamic factor demand. Although this has a number of advantages, i.e. it is flexible with respect to the underlying production structure and adjustment cost function, it allows for interrelated adjustment cost parameters and it is straightforward to generate closed form decision rules, it has a number of drawbacks as well. First, the adjustment cost function is not explicitly specified, so that it is not possible to analyse the structure of the adjustment cost function. Second, most dynamic dual studies are based on static price expectations and therefore subject to the Lucas' critique (1976). Although some progress has been made on incorporating non-static expectations (Luh and Stefanou, 1996; Pietola and Myers, 2000) this usually requires the assessment of expectations outside the model. An alternative (primal) approach is to derive necessary conditions for an optimum and estimate these optimality conditions directly (see e.g. Pindyck and Rotemberg 1983; Shapiro, 1986). Assuming that farmers form their expectations rationally, i.e. they know the underlying processes specified in the model, unobserved expected values of variables are replaced by their realised counterparts and an expectation error is added to the model. The advantage of this approach is that the adjustment cost function is specified explicitly, which allows for testing various adjustment cost specifications. This yields insight in the structure of the adjustment cost function and the nature of the adjustment process for different capital goods, taking differences in adjustment costs between farms into account.

The impact of manure production rights on investment

Quantitative restrictions on production may not only lead to lower utilisation of capital in the short run as discussed before, they may also reduce investment in the long run. Consequences of lower investments are that innovation is reduced, deteriorating the long-run productivity of the sector (Richards and Jeffrey, 1997) and that investments contributing to the solution of the manure problem are reduced (LNV, 1996). A number of studies have investigated the impact of supply quotas on investment (e.g. Stefanou et al., 1992 and Richards and Jeffrey, 1997). In these studies it is assumed that supply quotas are binding. However, in some cases it is not obvious that quotas are binding. In that case the relevant question is not what the effect of supply quotas on investments is, but whether there is such an effect at all. An example is the introduction of manure production rights in the Dutch pig sector in 1987. Given the close relationship between pig production and manure production, a system of manure production rights also implies a constraint on pig production. However, although the growth in pig numbers, which started in the 1970's and accelerated in the 1980's, was halted and average investment was somewhat lower after 1987, it is not well understood whether investments were reduced by an implicit output constraint or not. The quantity of manure production rights was allotted on the basis of historical production levels which farmers had to report themselves. Farmers may have come up with numbers based on maximum production capacity instead of historical production levels, thus creating future possibilities for expansion of production (Frouws, 1994). Furthermore, the decrease in investment may have had other causes. Low output prices may have reduced expected gains from investment or deteriorated the financial situation of farmers. Therefore, it is interesting to test whether reductions in investment arose from the system of manure production rights, or whether other factors have caused the slow-down in farm investment.

1.2 Objectives of the thesis

The objective of this thesis is to study capital adjustment on individual pig farms in the Netherlands, taking farm-specific characteristics into account. In order to study this process, micro-economic models are constructed and estimated. From this broad objective, four specific objectives are defined and worked out in the subsequent chapters. The motivation for these specific objectives is given in the previous section.

The first objective of this thesis is to investigate the relation between the unobserved management variable and quasi-fixed factors (e.g. capital) on specialised pig breeding farms, using the Hausman-Taylor panel data estimator that is extended for estimating a system of output supply and input demand equations with unbalanced panel data.

In 1998 the introduction of the pig sector restructuring law led to short-run under-utilisation of quasi-fixed factors on individual pig farms. The second objective is to investigate the short-run effect of reduced utilisation of quasi-fixed factors on shadow prices of production and shadow prices of supply quotas.

The third objective is to analyse the structure of adjustment costs for buildings and machinery on Dutch pig farms using a generalised investment model, which assumes that farmers have farm-specific thresholds for investment and face adjustment costs when they invest. Alternative specifications for the adjustment cost functions of buildings and machinery are tested for.

The fourth objective is to test whether manure production rights constrained capital investment on Dutch pig farms over the period 1987-1996 through an indirect constraint on production. If investments were reduced by these manure production rights, this may have reduced the future viability of the pig sector.

1.3 Outline of the thesis

In this section the main contents of chapters 2-5 are given. These chapters were originally written as stand-alone papers and were submitted to journals for publication. Therefore, some overlap between the chapters, particularly in data description, is inevitable.

In chapter two the relation between the unobserved farm-specific effects, accounting for differences in management, and quasi-fixed factors is investigated using the Hausman-Taylor panel data estimator. Chapter three develops a theoretical model to analyse the short-run effects of factor under-utilisation on the shadow price of production and the shadow price of supply quotas. The model is used to simulate prices of pig rights for pig breeding farms introduced by the 1998 pig sector restructuring law with and without taking factor under-utilisation into account. In the subsequent chapters capital adjustment is explicitly modelled using a generalised model of investment that combines fixed asset theory and adjustment cost theory. In chapter four the structure of adjustment costs for buildings and machinery is investigated, using a flexible adjustment cost specification and assuming farm-specific thresholds for investment. Chapter five addresses the question whether the system of manure production rights introduced in 1987 has had an impact on capital investment. In chapter six the main conclusions of this thesis are summarised and two main aspects of this thesis, i.e. theories of long-run adjustment of quasi-fixed factors and taking farm heterogeneity into account using panel data techniques, are discussed. This chapter ends with suggestions for future research.

CHAPTER 2

ESTIMATING MANAGERIAL ABILITY USING PANEL DATA: THE HAUSMAN-TAYLOR APPROACH[1]

2.1 Introduction

Agricultural enterprises typically operate under different geographical and climatological conditions and are operated by farm operators that have different technical and managerial skills. Managerial ability is often seen as a major determinant in agricultural production and as an important source of farm heterogeneity (for an extensive review see Rougoor et al., 1998). Consequently, many studies in the agricultural economics literature have focused on measuring managerial ability using farm level data. This chapter focuses on econometric approaches towards measuring managerial ability using panel data.

Mundlak (1961) introduced the fixed effects approach using a production function and interpreted the fixed farm effect as an unobservable farm-specific variable that accounts for differences between farms in quality of management. However, when using a production function, the fixed effects approach introduced by Mundlak assumes that managerial skills act as slope neutral supply shifters. This assumption has been criticised frequently (Muller, 1974; Kalirajan et al., 1996; Oude Lansink, 2000), since there is no reason to assume that management affects all inputs equally and neutrally. Kalirajan et al. (1996) estimated a production function with farm-specific intercept and slope parameters using a random coefficients model. Another approach is taken by Thijssen (1992), Boots et al. (1997) and Oude Lansink (2000) who estimated a dual system of input demand and output supply equations with a fixed effect in each equation. Oude Lansink (2000) shows that the underlying production function has a farm-specific intercept and slope parameters.

The fixed effects approach (denoted as FE) has gained considerable popularity in the literature for its ease of implementation and the fact that it gives consistent estimates if the specific effect is correlated with explanatory variables (e.g. quantity of land, labour and capital). However, the FE specification has important disadvantages. Its estimates are less efficient than the random effects estimates and, also important, fixed effects estimation does

---

[1] Paper by Gardebroek, C. and Oude Lansink, A.G.J.M., submitted for publication to *Empirical Economics*.

not allow for estimating parameters corresponding with time-invariant but farm-specific variables such as region, education level of the manager, and presence of successor (Hausman and Taylor, 1981). The random effects (RE) approach is more efficient than the FE approach and allows for estimating time-invariant but farm-specific variables (Baltagi, 1995). However, the RE approach yields biased results when the farm-specific effect correlates with explanatory variables.

An alternative panel data estimator is proposed by Hausman and Taylor (1981; denoted as HT hereafter). The HT estimator gives consistent and efficient parameter estimates and enables the estimation of parameters associated with time-invariant, farm-specific variables. Furthermore, the HT approach avoids an ‘all or nothing’ choice between fixed and random effects; rather it explicitly accounts for the fact that some explanatory variables are correlated with the farm-specific effects and others are not. Importantly, the HT approach allows for performing tests on correlation of different sets of explanatory variables with the farm-specific effects.

The purpose of this chapter is twofold. First, the Hausman-Taylor estimator is developed for estimation of a system of equations on unbalanced panel data. Systems of equations are often encountered in the economics literature (e.g. systems of input demand and output supply equations) and unbalanced panel data are more frequently available than balanced panel data (and are also used in this study). Where system estimators for unbalanced panel data are available for FE and RE estimation (see Ivaldi et al. (1996) for RE), a system estimator has not been developed for HT estimation on unbalanced panel data.

The second purpose of this chapter is to employ the HT approach to perform statistical tests on correlation between quasi-fixed factors and the unobservable farm-specific effects in a dual system of input demand and output supply equations of Dutch specialised pig breeding farms. These farm-specific effects principally represent the unobservable management variable. Testing for correlation of different sets of inputs with the farm-specific effect allows for inferring information about the nature of the management variable. Previous research (Verstegen et al., 1995) has demonstrated that there are substantial differences in managerial ability between sow farmers in the Netherlands. However, information about the sources of differences in management quality is still lacking.

The remainder of the chapter is constructed as follows. Section 2.2 discusses the HT approach that is used in this chapter. It is shown how the estimator should be adapted to obtain consistent estimates with unbalanced panel data. The presentation of the empirical model follows in section 2.3 and a discussion of the data is given in section 2.4. In section 2.5

the relations between farm-specific effects and the quasi-fixed factors are discussed and the results of the estimations are given. The chapter ends with conclusions and comments.

2.2 Hausman-Taylor estimation of a system of equations with unbalanced panel data.

This section develops the framework for the estimation of a system of equations on unbalanced panel data using the approach developed by Hausman and Taylor (1981). However, before this extension is made, the Hausman-Taylor estimation approach is explained in the context of a single equation with balanced panel data.

The single equation Hausman-Taylor approach for balanced panel data

A balanced panel data set typically consists of *N* individuals, each represented in the data set for *T* time periods. The following general equation corresponds to individual *i* at time *t*:

$$\begin{aligned} y_{it} &= a + X_{it} b + Z_i g + e_{it} \\ e_{it} &= m_i + u_{it} \end{aligned} \qquad (2.1)$$

In (2.1), y_{it} is an element of a *NT* vector of endogenous variables, X_{it} is an element of a *NT´k* matrix of variables varying over time and individuals (e.g. quantity of fertiliser used per farmer per year, income per head per year) and Z_i is an element of a *NT´g* matrix of variables varying over individuals only (e.g. region, education level, presence of successor). Furthermore, a is an intercept term, b and g are respectively *k´1* and *g´1* vectors of parameters and e_{it} is the composite error term, consisting of a farm-specific effect m_i and the conventional error u_{it}. In order to explain the Hausman-Taylor estimator and to clarify the drawbacks of the standard FE and RE estimators for equation (2.1), *X* and *Z* are partitioned into two sets of variables: $X = \left[X_1; X_2\right]$ and $Z = \left[Z_1; Z_2\right]$ where X_1 is *NT´*k_1, X_2 is *NT´*k_2, Z_1 is *NT´*g_1 and Z_2 is *NT´*g_2. X_1 and Z_1 are assumed to be fully exogenous i.e. they do not correlate with both m_i and u_{it}. X_2 and Z_2 are endogenous because they correlate with m_i but not with u_{it}.

An estimator that can estimate all parameters in equation (2.1) is the random effects estimator. However, this estimator is biased since it assumes that all explanatory variables are uncorrelated with the farm-specific effect. Note that the RE estimator implies that X_2 and Z_2 are empty. The bias induced by the correlation of X_2 and Z_2 with m_i can be overcome by applying a fixed effects estimator. It is implemented by transforming all variables into deviations from the individual means (within transformation) and applying OLS to the transformed equation. However, the within transformation also removes the parameter a and the vectors Z_1 and Z_2, implying that the parameter vector g cannot be estimated. Moreover, the FE estimator is not efficient since it disregards variation between individuals.

In order to obtain efficient and consistent estimates for all parameters in (2.1), Hausman and Taylor first transform the data by multiplying all variables in (2.1) by $s_u \Omega^{-1/2}$:

$$s_u \Omega^{-1/2} y = s_u \Omega^{-1/2} a + s_u \Omega^{-1/2} Xb + s_u \Omega^{-1/2} Zg + s_u \Omega^{-1/2} m + s_u \Omega^{-1/2} u \tag{2.2}$$

where Ω is a block-diagonal covariance matrix of the composite disturbances. With the variance of m_i denoted by s_m^2 and the variance of u_{it} denoted by s_u^2, Baltagi (1995: 14) shows that $\Omega^{-1/2}$ is given by:

$$\Omega^{-1/2} = \frac{1}{s_u}\left(Q_{NT} + qP_{NT}\right) \qquad with \quad q = \sqrt{s_u^2 / \left(s_u^2 + Ts_m^2\right)} \tag{2.3}$$

Matrix Q_{NT} transforms data into deviations from individual means and P_{NT} transforms data into individual means:

$$Q_{NT} = I_{NT} - P_{NT} \qquad\qquad P_{NT} = \left[I_N \otimes \frac{1}{T} J_T\right] \tag{2.4}$$

Note that I denotes an identity matrix and that J_T is defined as a $T´T$ matrix of ones. Using (2.3) and (2.4), (2.2) is expressed in a more convenient form as:

$$y_{it} - (1-q)\bar{y}_i = qa + \left(X_{it} - (1-q)\bar{X}_{i.}\right)b + qZ_i g + qm_i + \left(u_{it} - (1-q)\bar{u}_{it}\right) \tag{2.5}$$

In order to deal with the endogeneity of X_2 and Z_2, Hausman and Taylor propose an instrumental variables estimator, using an instrument set consisting of deviations from means of time-varying variables ($Q_{NT}X_1$, $Q_{NT}X_2$), means of exogenous time-varying variables ($P_{NT}X_1$) and levels of exogenous time-invariant variables (Z_1) (Breusch, Mizon and Schmidt, 1989).

Consistent and efficient estimates of both b and g can be obtained, if the condition $k_1 \geq g_2$ holds, i.e. the number of instruments should be greater than or equal to the number of endogenous variables. It is important to recognise that all instruments are provided by the variables in the model[2]. Using this instrument set, it can be shown that FE and RE are special cases of the general HT method. With FE, q is zero and the relevant instrument set is only $[Q_{NT}X_1, Q_{NT}X_2]$. RE on the transformed equations, assuming X_2 and Z_2 empty, implies an instrument set $[Q_{NT}X_1, P_{NT}X_1, Z_1]$.

In order to construct $\Omega^{-\frac{1}{2}}$, consistent estimates for s_m^2 and s_u^2 are required. An estimate for s_u^2 is obtained using within estimation residuals. Using the within parameter estimates and data transformed into individual means an estimate for s_m^2 is obtained.

Hausman-Taylor estimation of a system of equations with unbalanced panel data

Applied economic work frequently involves the estimation of a system of equations (e.g. a system of output supply and input demand equations for producers or a system of demand equations for consumers). Consistent estimates of parameters in systems of equations can be obtained using single-equation estimation techniques. However, usually these estimates are not efficient, since they do not take into account correlation of disturbances u_{it} across equations (see e.g. Judge et al, 1985: 468). So far, the literature does not provide a Hausman-Taylor estimator for systems of equations on unbalanced panel data[3].

In order to denote the different equations an equation subscript j (j=1..G) is added to equation (2.1). The major implication of having a system of equations is that the disturbances may be correlated across equations. If Σ_υ and Σ_μ are defined as the $G´G$ covariance matrices of respectively u_{ijt} and m_{ij} across equations, the complete $GNT´GNT$ covariance matrix in the balanced case is defined as:

$$\Omega = \Sigma_u \otimes I_{NT} + \Sigma_m \otimes (I_N \otimes J_T) = \Sigma_u \otimes Q_{NT} + \Sigma_1 \otimes P_{NT} \tag{2.8}$$

---

[2] Amemiya and MaCurdy (1986) and Breusch, Mizon and Schmidt (1989) proposed more efficient sets of instruments, both requiring stronger exogeneity restrictions on the instruments. Because the gains in efficiency turn out to be relatively small (Cornwell and Rupert, 1988; Baltagi and Khanti-Akom, 1990) these alternative sets of instruments are not considered here.

[3] See Gardner (1998) for a discussion on Hausman-Taylor single equation estimation with unbalanced data.

where $\Sigma_1 \equiv \Sigma_\upsilon + T\Sigma_\mu$ (Baltagi, 1995:104). The inverse of the covariance matrix can be obtained since it holds that $\Omega^r = \Sigma_u^r \otimes Q_v + \Sigma_1^r \otimes P_v$, where r denotes any power. With unbalanced data, the number of periods T in the panel differs by cross-section units. Major implications are that the covariance matrix now consists of N blocks with size $GT_i \times GT_i$, and that the matrix Σ_1 is now individual specific and defined as $\Sigma_{1i} \equiv \Sigma_\upsilon + T_i\Sigma_\mu$. The following approach is taken in order to account for different numbers of years[4]. First, the data is stacked by individual (with time index going fast and the equation index going slow, i.e. $\sum_{i=1}^{N}\sum_{j=1}^{G}\sum_{t=1}^{T_i} y_{ijt}$). With cross-equation covariance the same for all individuals, individual covariance matrix blocks with dimensions $GT_i \times GT_i$ are specified:

$$\begin{aligned}\Omega_i &= \Sigma_u \otimes I_{T_i} + \Sigma_m \otimes J_{T_i} = \Sigma_u \otimes I_{T_i} + T_i\Sigma_m \otimes \bar{J}_{T_i} = \left(T_i\Sigma_m + \Sigma_u\right) \otimes \bar{J}_{T_i} + \Sigma_u \otimes E_{T_i} \\ &= \Sigma_{1i} \otimes \bar{J}_{T_i} + \Sigma_u \otimes E_{T_i}\end{aligned} \tag{2.9}$$

where $\bar{J}_{T_i}$ is defined as J_{T_i}/T_i and E_{T_i} is $\left(I_{T_i} - \bar{J}_{T_i}\right)$. This result follows directly from (2.8) by assuming we have only one individual so I_N reduces to one. Note that with T_i differing for individuals, Σ_{1i} is individual specific. From (2.9) find

$$\Omega_i^{-1} = \Sigma_{1i}^{-1} \otimes \bar{J}_{T_i} + \Sigma_u^{-1} \otimes E_{T_i} \quad \text{and} \quad \Omega_i^{-1/2} = \Sigma_{1i}^{-1/2} \otimes \bar{J}_{T_i} + \Sigma_u^{-1/2} \otimes E_{T_i} \tag{2.10}$$

The last expression in (2.10) is used to transform the individual GT_i vectors of data:

$$w_i^* = \Omega_i^{-1/2} \cdot w_i = \left(\Sigma_{1i}^{-1/2} \otimes \bar{J}_{T_i} + \Sigma_u^{-1/2} \otimes E_{T_i}\right) w_i \tag{2.11}$$

where w_i is any variable in the system. Creating a block diagonal matrix $\Omega^{-1/2}$ of the individual matrices $\Omega_i^{-1/2}$, total vectors of data can be transformed. This GLS transformation incorporates both the transformation for cross-equation correlations and the transformation of the compound error terms (noise error and farm-specific effect). After this transformation, the

[4] Ivaldi et al (1996) use a similar procedure in the case of RE estimation of a system of equations with unbalanced data.

system of equations is written as a single equation with $G \cdot \sum_{i=1}^{N} T_i$ observations and a single equation estimation method is used to obtain parameter estimates. This procedure is equivalent to using the following 3SLS estimator:

$$
\begin{aligned}
(\hat{a}, \hat{b}, \hat{g}) &= \left[\sum_{i=1}^{n} \Omega_i^{-1/2} (i_i, X_i, Z_i)' R_{Ai} (i_i, X_i, Z_i) \Omega_i^{-1/2} \right]^{-1} \sum_{i=1}^{n} \Omega_i^{-1/2} (i_i, X_i, Z_i)' R_{Ai} y_i \Omega_i^{-1/2} \\
&= \left[\sum_{i=1}^{n} (i_i^*, X_i^*, Z_i^*)' R_{Ai} (i_i^*, X_i^*, Z_i^*) \right]^{-1} \sum_{i=1}^{n} (i_i^*, X_i^*, Z_i^*)' R_{Ai} y_i^*
\end{aligned}
\tag{2.12}
$$

where i_i is a vector of ones corresponding with the intercept and where R_A denotes a transformation by the instrument set $\left[E_{GT_i} X_{1i}, E_{GT_i} X_{2i}, \Sigma_{i1}^{-1/2} \otimes \bar{J}_{T_i} X_{1i}, \Sigma_{i1}^{-1/2} \otimes I_{T_i} Z_{1i} \right]$. Using this instrument set gives unbiased and consistent estimates, which is implied by the construction of the instruments. Recall that X_1 and Z_1 do not correlate with both m_{ij} and u_{ijt}, so that information contained in the individual means and in deviations from means can be used. Although X_2 is correlated with m_{ij}, deviations from the individual means used here are orthogonal to the farm-specific effects. Given that the unbalanced HT system estimator (2.12) is unbiased, it is also the most efficient unbiased (Gauss-Markov) estimator. Within and between information is optimally used and taken into account by the GLS transformation given in equation (2.11). Furthermore, taking cross-equation correlation among errors into account ensures more efficient estimates than single-equation estimates.

In order to construct the individual specific covariance matrix and its inverse, consistent estimates of the matrices Σ_υ and Σ_{1i} are needed. These matrices can be obtained using the following procedure. First, estimate the equations using single equation techniques to obtain vectors of disturbances *U*. If RHS variables are correlated with errors, 2SLS should be used. Using the single equation errors, a consistent estimate for Σ_u is obtained by:

$$
\hat{\Sigma}_u = \hat{U} Q_v \hat{U} / \left(\sum_{i=1}^{N} T_i - N - K \right)
\tag{2.13}
$$

Next, construct the cross-equation covariance matrix for between errors, denoted as Σ_2:

$$\hat{\Sigma}_2 = \hat{U}P_v\hat{U} / (N - K) \tag{2.14}$$

Extending Greene’s argument for obtaining the variance of the specific effects in the unbalanced single equation case (Greene, 1997: 634) to the multiple equation case a consistent estimate for Σ_m is obtained in the following way:

$$\hat{\Sigma}_m = \hat{\Sigma}_2 - \hat{\Sigma}_u \ \text{plim}\, \frac{1}{N}\sum_{i=1}^{N}\frac{1}{T_i} \tag{2.15}$$

Note that a consistent estimate of $\hat{\Sigma}_m$ is obtained if $\text{plim}\, \frac{1}{N}\sum_{i=1}^{N}\frac{1}{T_i}$ exists. Therefore, the number of years a farm is in the panel has to be distributed randomly across individuals around a mean of *T*, i.e. $\text{plim}\, \frac{1}{N}\sum_{i=1}^{N}\frac{1}{T_i} = \frac{1}{T}$. Using $\hat{\Sigma}_u$, $\hat{\Sigma}_m$ and the frequency of each farm in the sample, individual $\hat{\Sigma}_{1i}$ can be constructed, which in turn are used to obtain the individual $\Omega_i^{-1/2}$ as given in (2.10).

The farm-specific effects can be predicted using the ratio of the specific effect variance to the total between error variance (Judge et al., 1985: 524). Adapting this predictor to the system of equations case with unbalanced data yields:

$$\hat{m}_{ij} = \left(\frac{s^2_{m,j}}{s^2_{1,ij}}\right) i'_{T_i}\left(y_{ij} - a_{ij} - X_{ij}\hat{b}_j - Z_{ij}\hat{g}_j\right) \tag{2.16}$$

where $\hat{m}_{ij}$ is the predicted specific effect of farm *i* for equation *j*, $s^2_{m,j}$ is the variance of specific effects for equation *j*, $s^2_{1,ij}$ is defined as $T_i s^2_{m,j} + s^2_{u,j}$ and i_{T_i} is a T_i vector of ones.

2.3 Empirical model

In order to assess the relation between quasi-fixed factors and managerial ability of pig breeding farmers in the Netherlands, a system of netput equations is estimated using the

Hausman-Taylor approach. The model starts with the specification of a Symmetric Normalised Quadratic (SNQ) profit function. The SNQ is a flexible functional form that allows for negative profits and zero observations of netputs (Kohli, 1993)[5]. Furthermore, the SNQ parameter estimates are invariant to the choice of numeraire, as opposed to the normalised quadratic functional form (Diewert and Wales, 1987). Three netputs: pig output (q_1), feed input (q_2) and other variable input (q_3) and five quasi-fixed factors are included: labour of the farm family (z_1), buildings (z_2), machinery (z_3), land (z_4) and technological change represented by a time trend (z_5). In the Netherlands, pig production is mainly concentrated in two production regions, one located in the south of the Netherlands and one in the east. It is expected that production structure in terms of average farm size and farm organisation differs between these regions and with the rest of the Netherlands. Therefore, regional dummies are included, representing the eastern concentration region (z_6=1), the southern concentration region (z_7=1) and the rest of the Netherlands (z_6=0 and z_7=0). The SNQ profit function is defined as:

$$\begin{aligned} p_{it} = {} & \sum_{j=1}^{3}\left(a_j + m_{ij}\right) p_{jt} + \tfrac{1}{2}\left(\sum_{j=1}^{3} l_j p_{jt}\right)^{-1} \sum_{j=1}^{3}\sum_{k=1}^{3} a_{jk}\, p_{jt}\, p_{kt} \\ & + \tfrac{1}{2}\left(\sum_{j=1}^{3} l_j p_{jt}\right) \sum_{j=1}^{5}\sum_{k=1}^{7} b_{jk}\, z_{ijt}\, z_{ikt} + \sum_{j=1}^{3}\sum_{k=1}^{7} j_{jk}\, p_{jt}\, z_{ikt} \end{aligned} \tag{2.17}$$

where p_{it} are profits of farm *i* at time *t* and p_{jt} is the price of netput *j*. Linear homogeneity in prices is imposed by the fixed-weight price index $\sum_{j=1}^{3} l_j p_{jt}$, where l_j is the average share of netput *j* in total cost plus revenue. Symmetry is imposed by requiring that $a_{jk}=a_{kj}$ and $b_{jk}=b_{kj}$ for all *j* and *k*. The parameter m_{ij} is a farm-specific slope shifter. Note that the specification of the SNQ implies that prices vary over years and not over farms. Corresponding netput equations are derived using Hotelling's Lemma where an error term e_{ijt} is added:

[5] Note that the translog and Generalised Leontief do not have these properties.

$$q_{ijt} = \frac{\P p_{it}}{\P p_{jt}} = a_j + m_{ij} + \left(\sum_{j=1}^{3} l_j p_{jt} \right)^{-1} \sum_{k=1}^{3} a_{jk} p_{kt} - \tfrac{1}{2} l_j \left(\sum_{j=1}^{3} l_j p_{jt} \right)^{-2} \sum_{j=1}^{3} \sum_{k=1}^{3} a_{jk} p_{jt} p_{kt} + \tfrac{1}{2} l_j \sum_{j=1}^{5} \sum_{k=1}^{7} b_{jk} z_{ijt} z_{ikt} + \sum_{k=1}^{7} j_{jk} z_{ikt} + e_{ijt} \qquad (2.18)$$

Note that the farm-specific effects m_{ij}, which enter additively in the netput equations, interact with the netput prices in the profit function. The system of equations (2.18) was transformed and estimated as described in the previous section[6].

2.4 Data

Data on specialised pig breeding farms covering the period 1980-1996 are obtained from a stratified sample of Dutch farms keeping accounts on behalf of the farm accounting system of the Dutch Agricultural Economics Research Institute (LEI). Specialised pig breeding farms are defined as farms having a share of pig output in total output exceeding 80% and a share of breeding pig feed in total purchased feed exceeding 70%. The data set used for estimation contains 735 observations on 186 farms. One output and two variable inputs (feed and other variable inputs) are distinguished. Outputs are combined in an aggregate index covering all animal outputs (mainly piglets) and marketable crops. Other variable inputs consist of interest paid on the stock of animals, contract work, hired labour, veterinary services, heating costs, electricity and some minor other variable inputs. Quasi-fixed factors are labour, capital invested in buildings, capital invested in machinery and total land. Labour is measured in hours, and includes all family labour. Capital is measured at constant 1980 prices and land is measured in hectares.

Tornquist price indices are calculated for output and the inputs with prices obtained from LEI/Statistics Netherlands (several years). The price indices vary over the years but not over the farms, implying differences in the composition of a netput or quality differences are reflected in the quantity (Cox and Wohlgenant, 1986). Implicit netput quantity indexes are generated as the ratio of value to the price index. A summary of the data used is given in table I.1 of appendix I.

---

[6] The estimation procedure is written in SAS/IML, which has the advantage that it can be combined with other features of SAS. To obtain the matrices $\hat{\Sigma}_u^{-1/2}$ and $\hat{\Sigma}_{1i}^{-1/2}$ MATLAB is used.

The panel of pig breeding farms used is unbalanced. Whether the non-response in the unbalanced panel, caused by voluntary exit or removal, has an impact on the random design and the representativeness of the panel, depends upon whether the selection rule is ignorable or non-ignorable (Verbeek and Nijman, 1992a). In the former case, standard panel data methods can be used in order to obtain consistent estimates. In the latter case the response mechanism has to be taken into account explicitly in the estimation procedure. Verbeek and Nijman (1992b) propose a number of simple tests to test for the impact of selection bias in unbalanced panels. A test on selection bias is also performed in this chapter.

2.5 Results

The transformed system of equations given in (2.18) is estimated using the fixed effects, the random effects and the Hausman-Taylor approach. The RE approach assumes that all explanatory variables are orthogonal to the farm-specific effects and gives biased parameter estimates if this condition is violated. If H_0: $E(\mu_{ij}|X_{ijt}, Z_{ij})=0$ holds, then both the FE and the RE estimator are consistent, but the RE estimator is more efficient. Also, if H_0 is accepted, there is no need to apply the Hausman-Taylor model. However, if H_0 is rejected, the RE estimator yields inconsistent estimates, whereas the FE model still gives consistent estimates.

A Hausman test (Hausman, 1978) is used to test on correlation between the whole set of explanatory variables and the farm-specific effects. The test-statistic is defined as:

$$m = \left(\hat{\beta}_{RE} - \hat{\beta}_{FE}\right)' \left[\mathrm{var}\left(\hat{\beta}_{FE}\right) - \mathrm{var}\left(\hat{\beta}_{RE}\right)\right] \left(\hat{\beta}_{RE} - \hat{\beta}_{FE}\right) \qquad (2.20)$$

which is asymptotically distributed as χ^2_K. If H_0 is rejected, the assumption in RE estimation of the absence of correlation between explanatory variables and farm-specific effects is inappropriate.[7]

Testing the FE model versus the RE model yields a Hausman test statistic of 90.16, which exceeds $\chi^2_{43;0.95} = 59.02$. Therefore, the null hypothesis of zero correlation between the whole set of regressors and the farm-specific effects is rejected and it is concluded that the RE

[7] Note that this test-statistic can only be used if the vector of parameters and the covariance matrices have the same dimensions. In the random effects model the same number of parameters has to be included as in the fixed effects model.

estimates are biased. Note that the outcome of this test does not mean that all regressors correlate individually with the farm-specific effects. To obtain unbiased and efficient parameter estimates the Hausman-Taylor estimator should be used.

Correlation of a subset of explanatory variables with the farm-specific effects is tested by a Hausman-Taylor test (Hausman and Taylor, 1981). The hypothesis $E(\mu_{ij}|X_{1ijt}, Z_{1ij})=0$ is tested against the alternative $E(\mu_{ij}|X_{1ijt}, Z_{1ij})\neq 0$. If the null hypothesis holds, then both the FE and the HT estimator are consistent, but the HT estimator will be more efficient. The Hausman-Taylor test-statistic is defined as $\sigma_u^2 m$, where σ_u^2 is the variance of u of the system of equations and where m is defined as:

$$m = \left(\hat{\beta}_{HT} - \hat{\beta}_{FE}\right)' \left[\text{var}\left(\hat{\beta}_{FE}\right) - \text{var}\left(\hat{\beta}_{HT}\right)\right] \left(\hat{\beta}_{HT} - \hat{\beta}_{FE}\right) \quad (2.21)$$

Under H_0, $\sigma_u^2 m$ follows a χ_L^2 distribution with $L = \min\left[k_1 - g_2, N - K\right]$. Table 2.1 provides Hausman-Taylor test statistics of correlation between individual regressors (and their quadratic terms) and the farm-specific effects.

Table 2.1 Hausman-Taylor tests of correlation between the farm-specific effects and different sets of variables used as instruments.

H_0 : Unit specific effect not correlated with: [a]	Outcome test-statistic	n[b]	$\chi^2_{n;0.95}$	H_0 rejected or not
Labour (z_1, z_1z_1)	8.13	6	12.59	not rejected
Buildings (z_2, z_2z_2)	14.76	6	12.59	rejected
Machinery (z_3, z_3z_3)	13.81	6	12.59	rejected
Land (z_4, z_4z_4)	5.48	6	12.59	not rejected
Trend (z_5, z_5z_5)	6.51	6	12.59	not rejected
v_1, v_1v_1	6.08	6	12.59	not rejected
v_2, v_2v_2	6.44	6	12.59	not rejected
v_3, v_3v_3	6.14	6	12.59	not rejected

a. If a time-varying variable is not correlated with the farm-specific effect, it is included in the vector X_1. Its deviation from the mean and its mean value are used as instruments.

b. *n* is the number of over-identifying restrictions defined as m*(k1-g2), where *m* is the number of equations. Note that it is assumed there are no time invariant variables correlated with the specific effects, g2=0.

It can be seen from table 2.1 that the orthogonality condition, i.e. no correlation between subsets of regressors and the farm-specific effects, is rejected for buildings and machinery and installations; it is not rejected for netput prices, labour, land and technological change. The implication of these test results is that the management factor represented by the farm-specific effects is independent of the application of the quasi-fixed factors labour and land and of technological change. However, the management factor correlates with quantities of capital in buildings and machinery and installations. As a final check, the FE model is tested versus a HT model with the non-rejected set of instruments (v_1,v_2,v_3,z_1,z_4,z_5) using a Hausman test. This yields a Hausman test statistic of 40.70, which is less than $c^{2}_{43;0.95} = 59.02$. Therefore, the null hypothesis of zero correlation between all prices, labour, land and technological change, and the specific effects is accepted in the HT model, implying that the farm-specifics are not correlated with these variables.

Whereas the previous specification tests indicate correlation between the farm-specific effects in the three netput equations with buildings and machinery, it does not indicate the direction of this relation. Using forecasts of the specific effects in the non-rejected HT model, consistent with (2.16), Pearson correlation coefficients were calculated between the forecasted specific effects and the quasi-fixed factors for all observations (table 2.2). Recognising that the farm-specific effects interact with netput prices in the profit function (2.17), a combined effect on profits can also be calculated. Correlations of this total profit effect with quasi-fixed factors are also given in table 2.2:

Table 2.2 Pearson correlation coefficients between explanatory variables and farm-specific effects from the Hausman-Taylor model.

	Output	Feed	Other Inputs	Profit*
Labour	0.155**	-0.203**	-0.169**	-0.018
Buildings	0.609**	-0.582**	-0.619**	0.292**
Mach. and Inst.	0.576**	-0.529**	-0.591**	0.332**
Land	0.001	0.020	-0.045	-0.018
Trend	0.097**	-0.122**	-0.095	0.010
Dummy East	0.059	-0.062	-0.043	0.037
Dummy South	-0.049	0.058	0.032	-0.021

*) The combined profit effect is calculated as $m_{1h}^{x}p_1+m_{2h}^{x}p_2+m_{3h}^{x}p_3$
**) Significant at 5%.

The column headers output, feed and other inputs in table 2.2 refer to the farm-specific effects in the respective netput equations. A positive correlation of the production factors in the first column of table 2.2 with output (profit) implies that farms with (*ceteris paribus)* higher output (profit) have larger quantities of those factors as well. Feed and other inputs are measured as negative quantities. Therefore, a positive correlation implies that farms with *(ceteris paribus)* lower input demand have higher quantities of these factors. Since the profit effect includes the farm-specific effects of output and variable inputs, it can be seen as an overall measure for managerial ability.

The results in table 2.2 show that most factors have a positive correlation with the farm-specific effect of output (input). The correlation of the quasi-fixed factors buildings and machinery and installations with the farm-specific effects is significant (at the critical 5% level) and higher than correlation of the other quasi-fixed factors. Furthermore, it can be inferred from the correlation with profit that pig breeding farms with good management use significantly (at 5%) larger quantities of buildings and machinery and installations than farms with poor management. Farms with good and poor management do not differ significantly (at 5%) with respect to the application levels of labour and land and managerial ability does not differ much between regions and over time.

Parameter estimates and standard errors of the FE, RE and HT models are given in table I.2 of appendix I. The RE and HT methods allow for obtaining parameter estimates for the common intercepts of the output supply and input demand equations (a_i) and of the time-invariant regional dummy parameters g_{i6} and g_{i7}. Table I.2 shows that FE, RE and HT estimation yield slightly different parameter estimates. Not surprisingly, differences between HT and RE estimates are generally largest for parameters associated with buildings and machinery and installations (z_2 and z_3). Therefore, given the fact that RE is biased, it can be concluded that in this data set, the bias is restricted to parameters associated with the total stock of buildings and total stock of machinery. Also, as expected, all standard errors of the RE and the HT estimates are lower than the standard errors of the FE estimates. This confirms the greater efficiency of the HT estimator compared to the FE estimator. Analysis of the individual t-ratio's reveals that the number of parameters significant at the critical 5% level is 12 (28%) for the FE model, (16 at the 10% level), 14 (27%) for the RE model (18 at the 10% level) and 13 (25%) for the HT model (20 at the 10% level), respectively. From the additional 9 parameters in the RE and HT model, only 1 is significant at the 5% level. The profit function is found to be not convex in prices for each estimation method. However, none of the estimated price parameters is significant at the critical 5% level.

In order to test for selectivity bias a variable addition test was performed (Verbeek and Nijman, 1992b). This test has the advantage over other tests of selectivity bias that it is easy to implement and does not require the specification of a balanced subsample for comparison. The number of periods in the panel and a dummy indicating the presence of a farm in the previous period were added as variables in the regression. Both variables appeared to be not significant at the critical 5% level (p-values of respectively 0.67 and 0.83), providing evidence of absence of selectivity bias in the panel.

2.6 Conclusions and discussion

This chapter develops a Hausman-Taylor estimator for systems of equations on unbalanced panel data. The framework is applied to a panel of specialised pig breeding farms in the Netherlands over the period 1980-1996, in order to obtain insight in differences in management on those farms. The HT estimator is a panel data estimator that includes the fixed effects and random effects estimators as special cases. It gives consistent estimates and addresses the shortcomings of the frequently applied fixed effects estimator, i.e. loss of efficiency by ignoring variation between farms and inability to estimate parameters associated with variables that vary over individuals only. Moreover, it allows for performing tests on correlation between the unobserved farm-specific effects and quasi-fixed factors. Since Dutch pig breeding farmers differ mainly in technical skills and skills in organising the production process, together denoted by an aggregate management variable, the farm-specific effects principally represent the unobserved management variable.

Testing indicates that farm-specific effects in a system of output supply and input demand equations for Dutch pig breeding farms are correlated with buildings and machinery and installations. Therefore, it can be concluded that differences in management are related to different quantities of these capital goods. Results indicate that pig farms with good management have more buildings and machinery than pig farms with poor management. Although the correlation between management and the quantity of capital does not imply a direct causal relationship, it can be inferred that either good management is a major determinant in capital investment or that a large capital base enables a pig farmer to improve upon its management skills.

Correlation between capital in buildings and capital in machinery and installations with the farm-specific effects is responsible for the bias in the RE model. Moreover, the results further demonstrate that the HT method gives more efficient estimates than the frequently employed FE model and that the HT method allows for estimating parameters associated with variables that vary over individuals only. The availability of the HT estimator also avoids the ‘all or nothing’ choice between FE and RE that is often made by applied economists. Moreover, it is found that the HT estimation method is a valuable tool in testing for the nature of the unobserved management variable.

CHAPTER 3

QUOTA PRICES AND FACTOR UNDER-UTILISATION[1]

3.1 Introduction

Supply quotas are frequently applied in agricultural policy. In the European Union quota regimes exist for milk and sugar beets, the United States introduced quotas in the production of peanuts and tobacco and in Canada production of milk, poultry meat, eggs and tobacco is subjected to quotas. Numerous studies focusing on specific aspects of quotas have appeared. Babcock and Foster (1992) e.g. analyse the distribution of economic rents between quota owners and quota renters under changing marginal costs of production in U.S. tobacco production. Boots et al. (1997) concentrate on efficiency losses due to distortions in Dutch milk quota trade. Guyomard et al. (1996) investigate French milk quota trade and its effects on production decisions and farm income. Moschini (1988) analyses the effects of a number of quota regulated outputs on agricultural production in Canada whereas Rucker et al. (1995) focus on county-level demand for flue-cured tobacco quota and quota trade restrictions in the U.S. Some of these studies are performed at the individual farm level where others are at the aggregate (state or country) level.

A common feature of previous studies dealing with supply quota is that they ignore the effect of output rationing on factor utilisation in the short-run. It is clear that in producing a restricted quota quantity, which is well below the historical optimal production level, a smaller quantity of variable inputs is used. However, the quantity of quasi-fixed factors available in the short-run cannot be adjusted and therefore the farmer is forced to reduce the utilisation of the available quasi-fixed factors. In this chapter a model is developed where the introduction of a quota affects the utilisation of quasi-fixed factors, leading to a shift in the individual short-run supply curve[2]. This shift has implications for the shadow price of production and the derived shadow price of the supply quota in the short-run. In case of

---

[1] Paper by Gardebroek, C., Oude Lansink, A.G.J.M. and Peerlings, J.H.M., submitted for publication to *Cahiers d'Economie et Sociologie Rurales.*

[2] It is often recognised that supply curves shift due to the introduction of quota. Alston (1981) gives a number of reasons for a shifting supply curve in a quota system. Babcock and Foster (1992) take shifts of the marginal cost curve due to changes in variable input prices into account in their tobacco quota study. However, both papers do not recognise factor under-utilisation.

tradable supply quotas, this is relevant for pig farmers who buy or sell additional pig supply quotas. If quotas are not tradable, it is relevant for the government who buys out individual pig farmers, since it needs information on farmers' valuation of supply quotas.

The theoretical model developed in this chapter is applied to a sample of Dutch pig breeding farms. Quotas in the Dutch pig sector were introduced in September 1998 with the pig sector restructuring law, in order to curb emissions of phosphate and nitrate and to reduce the probability of pig disease outbreaks (e.g. classical swine fever). The quota level was set at 90% of the production level of 1996. In the short-run, this led to empty places in pig units and reduced utilisation of available labour. After introduction quota cannot be traded for a three-year period, with the exception of selling to the government (in order to reach a further output reduction). Because the shadow price of a supply quota gives the on-farm value of that quota, the government can base its price on the shadow prices of supply quota.

The remainder of this chapter is structured as follows. In section 3.2 the theory of output supply under rationing is elaborated. Starting from the basic theory as developed by Fulginiti and Perrin (1993), the case with factor under-utilisation is developed. In section 3.3 the empirical model, the data and some estimation issues are clarified. Section 3.4 describes the simulations performed and the simulation results. The chapter ends with conclusions and comments.

3.2 Theoretical model

This section develops a model of short-term profit maximisation. The basic model represents the situation with no quantitative restrictions on output. Next, it is shown how this model can be used to show the effects of the introduction of a system of quotas. Two situations are distinguished, i.e. one in which it is assumed that the quantity of quasi-fixed factors is fully utilised (as in Fulginiti and Perrin, 1993) and one in which it is assumed that the factor utilisation rate after the introduction of production rights differs from the full utilisation rate.

Unconstrained profit maximisation

Profit maximising behaviour of farms prior to the introduction of a quota system is represented by the following unconstrained profit function (p^u):

$$\pi^{u}\left(p_1, p_2, z\right) = \max_{q_1, q_2}\left(p_1 q_1 + p_2 q_2 : \left(q_1, q_2, z\right) \in T\right) \qquad (3.1)$$

where q_i and p_i are vectors of netput quantities (positive for outputs, negative for inputs) and corresponding netput prices, z is a vector of quasi-fixed factors and T is the technology set. The profit function is assumed to be positive, non-decreasing in output prices and quasi-fixed factors, non-increasing in input prices, linear homogeneous and convex in prices, continuous and twice differentiable in its arguments. Optimal levels of netputs as a function of prices are obtained by applying Hotelling's Lemma:

$$q_i^{u}\left(p_1, p_2, z\right) = \frac{\partial \pi^{u}\left(p_1, p_2, z\right)}{p_i} \qquad for\ i = 1,2 \qquad (3.2)$$

Constrained profit maximisation with full factor utilisation

Next it is assumed that a quota is introduced that restricts the quantity of q_2 at quota level $\bar{q}_2$. Constrained variable profit π^c is now defined as:

$$\pi^{c}(p_1, p_2, \bar{q}_2, z) = \pi^{p}(p_1, \bar{q}_2, z) + p_2 \bar{q}_2 \qquad (3.3)$$

The profit function $\pi^{p}(.)$, which is referred to as 'partial profit' function (Fulginiti and Perrin, 1993) has the same properties as the unrestricted profit function, except that it is independent of p_2 and not necessarily positive.

The unconstrained and quota-constrained profit functions can be linked by the concept of 'virtual' price. The virtual price is defined as the price p_v that would induce the farm, in the unconstrained case, to choose the netput quantity q_2 equal to the quota-constrained level $\bar{q}_2$. This price is also called the shadow price of production. Using this definition, and inserting p_v for p_2, the unconstrained profit function can be rewritten as:

$$\pi^{u}\left(p_1, p_v, z\right) = \pi^{p}\left(p_1, \bar{q}_2, z\right) + p_v \bar{q}_2 \qquad (3.4)$$

Applying Hotelling's lemma to (3.4) we find (at $p_2 = p_v$):

$$q_2^u\left(p_1, p_v, z\right) = \frac{\P\, p^{\,u}\left(p_1, p_v, z\right)}{p_v} = \bar{q}_2 \tag{3.5}$$

From equations (3.3) and (3.4) we can derive the relationship between constrained and unconstrained profits:

$$p^{\,c}\left(p_1, p_2, \bar{q}_2, z\right) = p^{\,u}\left(p_1, p_v, z\right) + \left(p_2 - p_v\right) \cdot \bar{q}_2 \tag{3.6}$$

Differentiating the constrained profit function (p^c) to the constrained quantity q_2 gives:

$$r_q = \frac{\P\, p^{\,c}}{\P\, \bar{q}_2} = \left(\frac{\P\, p^{\,u}}{\P\, p_v} - \bar{q}_2\right) \cdot \frac{\P\, p_v}{\P\, \bar{q}_2} + \left(p_2 - p_v\right) = \left(p_2 - p_v\right) \tag{3.7}$$

where p_2-p_v=r_q is the shadow price of the quota right, i.e. the price the farm is willing to pay for producing one additional unit of q_2. Inserting (3.7) in (3.6) gives:

$$p^{\,c} = p^{\,u}\left(p_1, p_2 - r_q, z\right) + r_q \cdot \bar{q}_2 \tag{3.8}$$

The slope of the curve that represents the relation between the shadow price of production and the quantity is given by (see Fulginiti and Perrin, 1993):

$$\frac{\partial p_v\,(p_1, \bar{q}_2, z)}{\partial \bar{q}_2} = \left(\frac{\partial q_2^u\,(p_1, p_v, z)}{\partial p_v}\right)^{-1} \tag{3.9}$$

which is the slope of the curve in figure 3.1. Assuming profit maximisation, this curve gives profit maximising supplies at various prices. In the unconstrained case at price p_2 it is optimal for a farmer to supply q_2. If output is constrained at quota level $\bar{q}_2$ due to the introduction of quota, the farmer cannot supply more than this $\bar{q}_2$ but will still receive p_2. This situation can be analysed considering the shadow price of supply p_v. In the unconstrained case the farmer would have supplied $\bar{q}_2$, if the price were p_v. Indicated by equation (3.7) the farmer obtains a rent (p_2-p_v) = r_q per unit of quota.

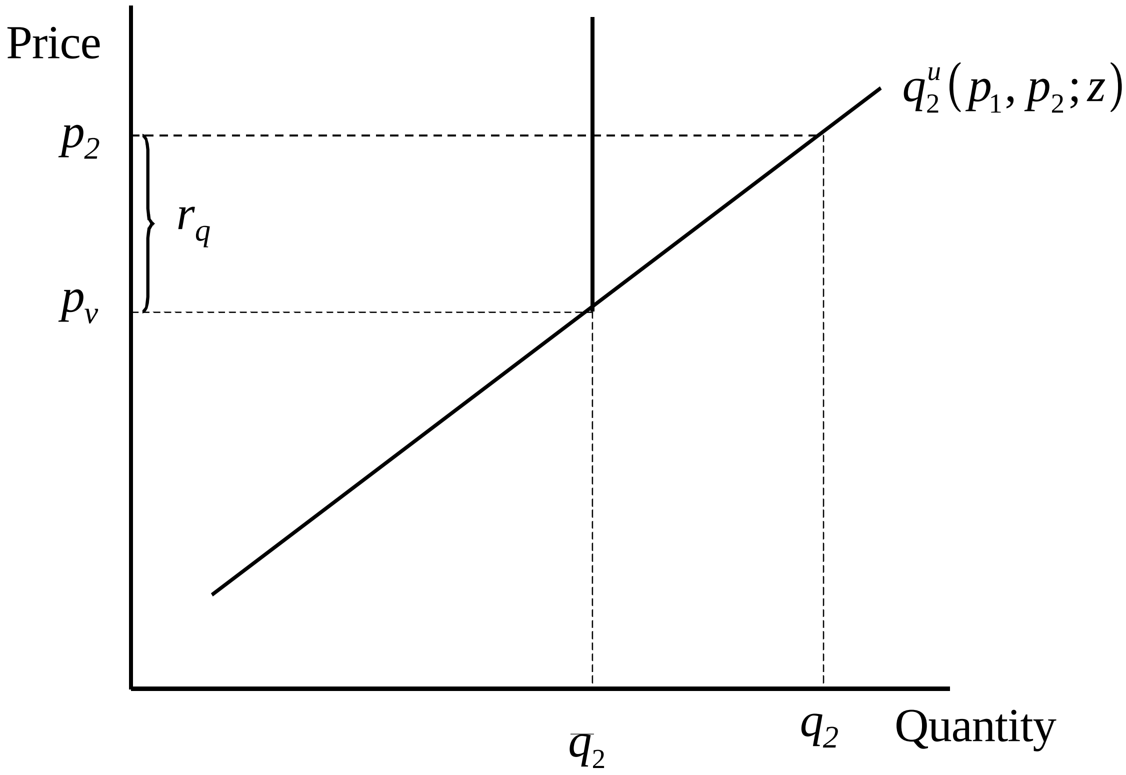

Figure 3.1 *Obtaining the virtual price of production from the marginal cost curve at quota* $\bar{q}_2$.

Constrained profit maximisation with factor under-utilisation

Short-term models of production are distinguished from long-term models by the assumption that some production factors are fixed in the short run, i.e. they cannot be adjusted to their optimal levels. If a farmer wants to expand production, the quasi-fixed factors are the constraining factors. If a supply quota is introduced however, and the quota level is less than the historical production level, the farmer may be faced with an excess capacity of production factors. The degree to which these factors are applied in production, which is less than the full quantity available, is defined as the factor utilisation rate[3]. In other words, the factor utilisation rate denotes that part of production factors that actually enters the production function. Although factor utilisation usually cannot be observed from the available data, it should be taken into account in cases where full utilisation cannot be assumed. This is the case when supply quotas are introduced in a situation where farmers already have decided on their capacity. Part of pig places and labour that are available cannot be used in actual production. Of course, when a quota is announced sufficiently in advance, farmers will anticipate this introduction by a different pace of investments in the years prior to the introduction (Stefanou, 1995). In that case, it may be assumed that the available factors are fully utilised under a quota restriction. However, if the time between the announcement of the quota and the actual introduction is short, the introduction of the quota will cause under-utilisation of the available factors on the farm in the short-run, i.e. in the period immediately after the introduction of the quota system. This situation also applies to the introduction of the pig quota system in the Netherlands where the 10% cut in pig quota was announced less than one year in advance. Part of the existing pig places and available family labour were not utilised in production and the characteristics of the production process prevented (full) substitution of variable inputs like animal feed or veterinary costs by the unutilised part of these quasi-fixed factors.

In order to take the effects of factor under-utilisation into account, the short-run efficient quantity of quasi-fixed factors (z^*) is defined as the product of the available fixed factor quantity, z, and the factor utilisation rate y, which is a function of the quota level:

$$z^* = y\,(\bar{q}_2) \cdot z \qquad \text{with} \quad \frac{\partial y\,(\bar{q}_2)}{\partial \bar{q}_2} \geq 0 \tag{3.10}$$

Note that differences in scale economies for different quasi-fixed factors imply that utilisation rates are not necessarily the same for all quasi-fixed factors given a certain restriction on output. The implication of factor under-utilisation is that in the short-run farmers can easily

---

[3] The factor utilisation rate is different from the capacity utilisation rate (Berndt and Morrison, 1981; Segerson and Squires, 1993). This capacity utilisation rate is a typical economic measure, comparing existing economic inefficient capacity to economic efficient capacity levels, where economic efficient means yielding minimum cost or maximum profits. Factor utilisation denotes the percentage of the available quantity of a production factor that is actually applied in production, which is a technical measure.

adjust the quasi-fixed factors in response to relaxing the quota restriction resulting in more elastic supply as long as the output level is below the unrestricted output quantity, q_2^*.

Inserting (3.10) in the constrained profit function gives:

$$p^c\left(p_1, p_2, \bar{q}_2, z^*\right) = p^u\left(p_1, p_v, z^*\right) + \left(p_2 - p_v\right) \cdot \bar{q}_2 \tag{3.11}$$

The slope of the marginal cost curve now contains an additional term due to the effect of the quota level on factor utilisation:

$$\frac{\partial p_v}{\partial \bar{q}_2} = \frac{\partial\ p_v(p_1, \bar{q}_2, z^*)}{\partial\ \bar{q}_2} + \frac{\partial\ p_v(p_1, \bar{q}_2, z^*)}{\partial\ z^*} \cdot \frac{\partial\ z^*}{\partial \bar{q}_2} \tag{3.12}$$

The term $\partial z^* / \partial \bar{q}_2$ is positive by assumption. Therefore, (3.12) implies that the slope of the marginal cost curve under full factor utilisation (see (3.9)) is adjusted upward or downward, depending on the sign of the term $\partial p_v(p, \bar{q}_2, z^*) / \partial z^*$. The term $\partial p_v(p, \bar{q}_2, z^*) / \partial z^*$ can be derived from the unconstrained profit function using:[4]

$$\partial p_v(p, \bar{q}_2, z^*) / \partial z^* = -\partial q_2 / \partial z \cdot \left(\partial q_2 / \partial p_v\right)^{-1} \tag{3.13}$$

In (3.13), the term $(\partial q_2 / \partial p_v)^{-1}$ is positive due to convexity of the unconstrained profit function in prices. Therefore, $\partial p_v(p, \bar{q}_2, z^*) / \partial z^*$ is negative if $\sum_{i=1}^{N} \partial q_2 / \partial z_i > 0$ and positive if $\sum_{i=1}^{N} \partial q_2 / \partial z_i < 0$. If q_2 is an output, it is expected that the first case prevails, i.e. quasi-fixed factors z_i increase q_2. Therefore, in our case the term $\partial p_v(p, \bar{q}_2, z^*) / \partial z^*$ is negative and factor under-utilisation decreases the slope of the marginal cost curve for an output under a quota. This situation is depicted by the kinked curve in figure 3.2 that results from shifts of the original marginal cost curve.

---

[4] This can be seen by differentiating (3.5) to z: $\frac{¶ p^u\left(p_1, p_v, z\right)^*}{\partial p_v \partial z^*} + \frac{\partial p^u(p_1, p_v, z^*)}{\partial p_v p_v} \cdot \frac{\partial p_v(p_1, \bar{q}_2, z^*)}{\partial z^*} = 0$

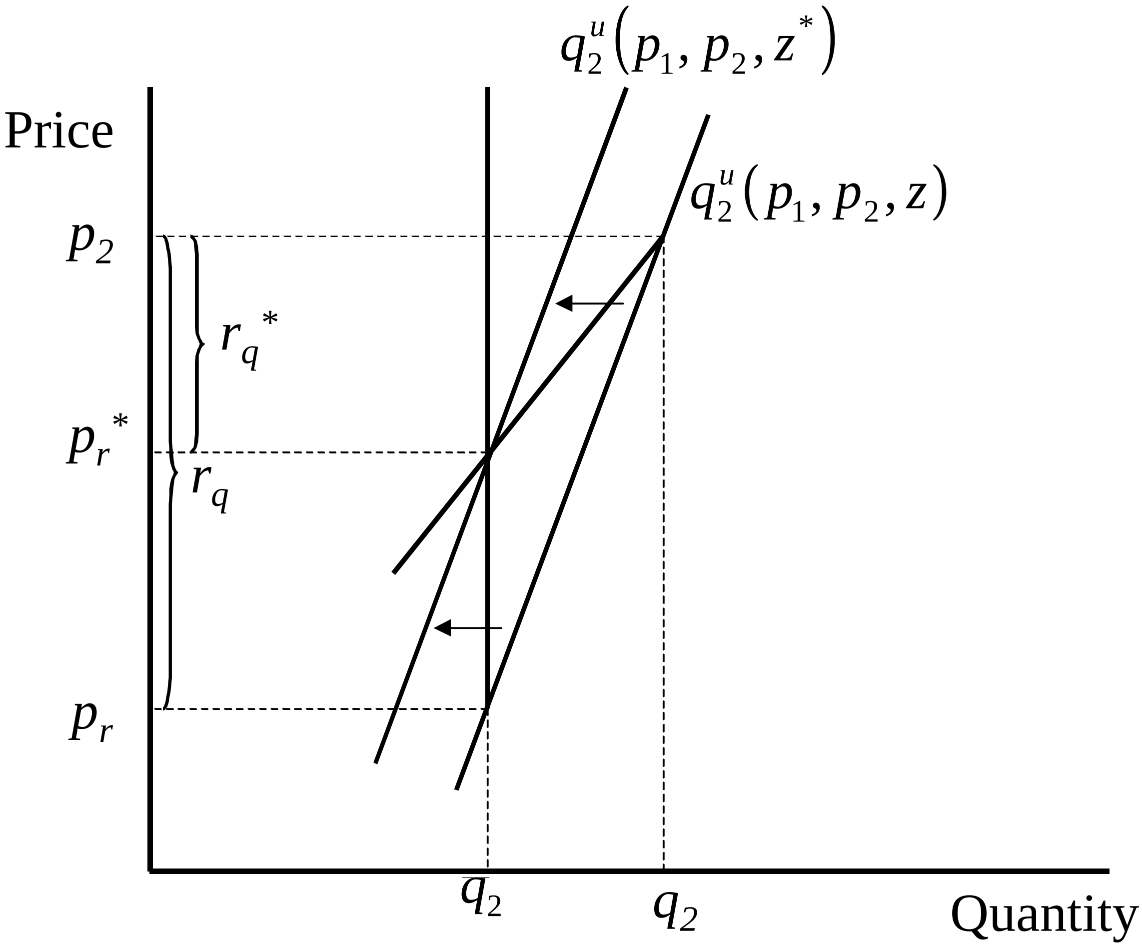

Figure 3.2 *A kinked marginal cost curve due to shifts in the original marginal cost curve.*

Factor under-utilisation also has implications for the shadow price of quota rights. Differentiating (3.11) gives:

$$r_q = \frac{\partial p^c}{\partial \bar{q}_2} = \left(\frac{\partial p^u}{\partial p_v} - \bar{q}_2 \right) \cdot \frac{\partial p_v}{\partial \bar{q}_2} + \frac{\partial p^u}{\partial z^*} \cdot \frac{\partial z^*}{\partial \bar{q}_2} + \left(p_2 - p_v \right) = \frac{\partial p^u}{\partial z^*} \cdot \frac{\partial y(\bar{q}_2)}{\partial \bar{q}_2} \cdot z + \left(p_2 - p_v \right) \qquad (3.14)$$

which implies that with factor under-utilisation, the shadow price of the quota rights is adjusted by the term $\partial p^{u} / \partial z^{*} \cdot \partial y(\cdot) / \partial \overline{q}_2$. Since $\partial y(\cdot) / \partial \overline{q}_2$ is positive, the sign of the total term depends on $\partial p^{u} / \partial z^{*}$, i.e. the vector of shadow prices of the under-utilised quasi-fixed factors. Economic theory predicts that shadow prices are positive, since the profit function is monotonically increasing in quasi-fixed factors. Therefore, factor under-utilisation decreases the price of the quota right. This implies that producers pay a lower price for additional quota if their factors are under-utilised compared to the case where their factors are not under-utilised due to a quota.

3.3 Empirical model, data and estimation

In this section an empirical model for Dutch pig breeding farms is specified. In section 3.4 the estimated model is used to simulate the effects of factor under-utilisation for Dutch pig farms under the 1998 pig sector restructuring law. Since prices of pig rights differ for pig breeding and pig fattening farms, only a subsample of pig breeding farms is used. First, the empirical model is specified, then the data is described and this section ends with a description of the estimation procedure.

Empirical model

The empirical model starts with the specification of the unconstrained profit function and its related functions. Using a symmetric normalised quadratic (Kohli, 1993; Oude Lansink and Thijssen, 1998), the short-run profit function is specified as

$$p_f = \sum_{i=1}^{3} a_{if} p_i + \tfrac{1}{2} \left(\sum_{k=1}^{3} q_k p_k \right)^{-1} \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij} p_i p_j + \tfrac{1}{2} \left(\sum_{k=1}^{3} q_k p_k \right) \sum_{i=1}^{5} \sum_{j=1}^{5} b_{ij} z_{if} z_{jf} + \sum_{i=1}^{3} \sum_{j=1}^{5} j_{ij} p_i z_{jf} \qquad (3.15)$$

where p_f are unconstrained profits at farm *f* and p_i are the netput prices of respectively pig output (mainly piglets) (i=1), pig feed (i=2) and other variable inputs (i=3). Short-run profits are specified given the level of quasi-fixed factors z_{jf} where j=1 is labour of the farm family, j=2 is buildings, j=3 is machinery, j=4 is land and j=5 is a trend denoting technological change. Linear homogeneity in prices is imposed by the fixed-weight price index $\sum_{k=1}^{3} q_k p_k$, where q_k is the average share of netput k in total cost plus revenue. Symmetry is imposed by requiring that $a_{ij}=a_{ji}$ and $b_{ij}=b_{ji}$ for all i and j. Convexity in prices requires the Hessian matrix to be positive semidefinite. Convexity in prices can be tested for or it can be imposed using the Wiley, Schmidt and Bramble (1973) technique.

Netput equations are derived by differentiating the profit function with respect to the corresponding prices (Hotelling's Lemma):

$$q_i = \frac{\P p_f}{\P p_i} = a_{if} + \left(\sum_{k=1}^{3} q_k p_k\right)^{-1} \sum_{j=1}^{3} a_{ij} p_j - \tfrac{1}{2} q_i \left(\sum_{k=1}^{3} q_k p_k\right)^{-2} \sum_{i=1}^{3}\sum_{j=1}^{3} a_{ij} p_i p_j + \tfrac{1}{2} q_i \sum_{i=1}^{5}\sum_{j=1}^{5} b_{ij} z_{if} z_{jf} + \sum_{j=1}^{5} j_{ij} z_{jf} \tag{3.16}$$

The three netput equations are the system of equations to be estimated. In order to identify all parameters, restrictions $\sum_{j=1}^{3} a_{ij} \overline{p}_j = 0$ have to be imposed (Diewert and Wales, 1987), where $\overline{p}_j$ is an arbitrary point observation. Shadow prices for the quasi-fixed factors are obtained from:

$$w_j^s = \frac{\P \Pi_f}{\P z_j} = \sum_{i=1}^{3} j_{ij} p_i + \left(\sum_{k=1}^{3} q_k p_k\right) \sum_{i=1}^{5} b_{ij} z_{if} \tag{3.17}$$

Data

Data on specialised pig breeding farms covering the period 1980-1996 are obtained from a stratified sample of Dutch farms keeping accounts on behalf of the Dutch farm accountancy data network. Farms are selected if the share of pig output in total output exceeds 80% and if the share of feed for pig breeding in purchased feed exceeds 70%. The farms typically remain in the panel for a maximum of five to seven years. The data set used for estimation contains 688 observations on 186 farms over the period 1980-1995. Data on 1996 was used for simulations. Outputs are combined in an aggregate index covering all animal outputs (mainly piglets) and marketable crops. Other variable inputs consist of hired labour, contract work, interest paid on livestock, veterinary services, heating costs, electricity and other variable inputs. Quasi-fixed factors are total family labour, capital invested in buildings, capital invested in machinery and land. Labour is measured in hours, capital is measured at constant 1980 prices, and land is measured in hectares.

Tornquist price indexes are calculated for output and inputs with prices obtained from the LEI/Statistics Netherlands (several years). The price indexes vary over the years but not over the farms, implying differences in the composition of a netput or quality differences are reflected in the quantity (Cox and Wohlgenant, 1986). Implicit quantity indexes are generated as the ratio of value to the price index. Information about the mean and standard deviation of the variables used in estimation can be found in appendix II.

Estimation

The panel structure of the data is taken into account by including a fixed effect in the netput equations. This farm-specific effect accounts for factors that affect the level of netputs supplied or demanded and which are not included explicitly in the model, e.g. the unobserved management variable. In principle the Hausman-Taylor estimator derived in chapter two could be used in estimation. However, since no time-invariant variables (e.g. region) are present in the model, and since interest is not on testing for specific correlation between the farm-specific effects and model variables, a standard fixed effects estimation procedure is used. As shown in chapter two this leads to less efficient estimates, but has the advantage that it is easy to implement. In order to account for the farm-specific effects and to avoid estimation of a model with a large set of dummy variables, the variables are transformed into deviations from the individual means. This implies that farms that appear only once in the data set are deleted.

In order to increase efficiency, the three netput equations are estimated together. Assuming the error terms to be uncorrelated with the quasi-fixed factors but correlated over equations, ITSUR is an appropriate estimation technique. This estimator converges to the ML estimator and iterates the covariance matrix until it stabilises (Magnus, 1978). In estimation 620 observations on 152 farms are used. Parameter estimates are given in appendix II, table II.2. At the 5% critical level 16 out of 33 parameter were significantly different from zero. The profit function is convex in prices.

3.4 Simulations and results

The estimated model is used to perform two simulations for individual pig breeding farms. First, the effects of a 10% reduction[5] in output keeping all netput prices fixed and all quasi-fixed factors fully utilised are shown. Second, the effects of a 10% reduction in output combined with a reduction in factor utilisation of labour, buildings and machinery are calculated. Since the relation between the quota and the factor utilisation rate is unobserved, it is assumed that the factor utilisation rates for these three quasi-fixed factors equal the ratio of the quota level, $\bar{q}_2$ to the unrestricted efficient quantity of output prior to the quota introduction, q_2^*:

$$y(\bar{q}_2) = \frac{\bar{q}_2}{q_2^*} \tag{3.18}$$

so $y(\bar{q}_2) = 0.90$ for all individual farms. Note that the true utilisation rates may be somewhat higher due to substitution possibilities between variable inputs and the unutilised quasi-fixed factors. Furthermore, the utilisation rates are not necessarily equal for all three quasi-fixed factors and for all farms. In this simulation all netput prices are kept fixed. Moreover, technology and the quantity of land (which is not used to produce pigs) are also kept constant.

Resulting quota prices from both simulations are given in table 3.1 together with the initial market price and simulated shadow prices of production. Although simulations are performed for individual farms, the average results are presented for farms in the two main production regions (South and East) and the rest of the Netherlands (Other)[6]. The results show that the shadow prices of quota rights are highest in the rest of the Netherlands. Most sample farms outside the main production regions are large intensive farms. Large intensive farms operate most efficient which results in the highest shadow prices of quota rights. It should be

---

[5] In the pig sector restructuring law a general reduction in output of 10% was imposed. However, the actual reduction in output is smaller than 10% for some farms because they received cutbacks in the reduction percentage if environmental and or animal welfare friendly buildings are used or they had a certain amount of land. Moreover, because the output is an aggregate of pig and other output (although the latter is small and often zero) a 10% overall reduction of the aggregate output is over-estimating the actual reduction for some farms.

[6] A model including region dummies interacting with prices and quasi-fixed factors was estimated. However, the parameter estimates were all highly insignificant and the model was rejected against the current model.

noted however that the results of the simulations depend on the high initial level of the output price. A lower initial output price leads to a lower price of pig quota rights.

Table 3.1 Average shadow prices of pig rights with full utilisation and under-utilisation of quasi-fixed factors and the percentage differences in the three regions and in total.

		Quota with full utilisation*	Quota with under-utilisation*	% Difference
Price for pig rights	South	0.82	0.62	-24%
	East	0.75	0.54	-28%
	Other	0.90	0.76	-16%
	Total	0.79	0.60	-24%

* Price index of pig production (base year 1980)

Table 3.1 shows that taking factor under-utilisation into account decreases the shadow price of pig quota rights by 24% on average, compared to the situation where factor under-utilisation is not accounted for. The results differ somewhat between regions. In the region East the effect on the shadow price is largest: taking under-utilisation into account decreases the shadow price by 28%. In the region Other the effect is only a decrease of 16%, whereas in the region South is it 24%.

The model is also used to simulate the effects of pig quota rights on profits and variable costs. Table 3.2 gives the percentage changes in profit and variable costs due to the quota introduction for full factor utilisation and factor under-utilisation. Total revenue is equal in both situations. It can be seen that, on average, short-term profit decreases more when factor under-utilisation is accounted for, because it takes into account that the actually used quantities of quasi-fixed factors are less than the available quantities. Furthermore, it can be seen that, on average, farmers use more variable inputs when factor under-utilisation is accounted for since substitution of variable inputs by the unutilised quantity of quasi-fixed factors is limited.

Table 3.2 Average levels of profits and total variable costs in 1996 and average percentage changes with full and under-utilisation of quasi-fixed factors in the three regions and in total.

		Pre quota value*	Quota with full utilisation	Quota with under-utilisation
Profit	South	2.32	-15.99	-17.15
	East	2.22	-16.41	-17.16
	Other	2.86	-18.62	-18.31
	Total	2.34	-16.61	-17.33
Variable costs	South	3.76	-6.52	-5.84
	East	3.49	-6.15	-5.70
	Other	5.03	-5.37	-5.54
	Total	3.79	-6.15	-5.72

* In 100.000 guilders of 1980

3.5 Conclusions and discussion

In this chapter a microeconomic model is developed in order to calculate the effects of the introduction of a quota system that causes under-utilisation of quasi-fixed factors. In the theoretical model it is shown that ignoring under-utilisation leads to overestimation of the shadow prices of quota rights. Factor under-utilisation is a short-term effect of a large reduction in production, due to the introduction of quotas. Faced with short-term constraints on adjusting the quantities of quasi-fixed factors, the farmer is forced to reduce the utilisation instead of the available quantities of quasi-fixed factors. In the long run, quantities of quasi-fixed factors can adjust towards new optimal levels.

The model was applied to the Dutch pig breeding sector where quotas were introduced in September 1998. Quota prices were calculated after a 10% reduction in quota rights for the situation assuming full factor utilisation and the situation of factor under-utilisation. Results show that ignoring factor under-utilisation overestimates quota prices on average by approximately 24%. Since the exact relationship between the reduction in production due to the quota and the factor under-utilisation rate is unobserved, it was assumed that the factor under-utilisation rate equals the initial output reduction. Further research is necessary to investigate the impact of a quota on the degree of factor utilisation. Such research should be performed at the time when quotas are introduced by registering the actual utilisation of available quantities of quasi-fixed factors.

This chapter shows that the occurrence of factor under-utilisation has important implications for short-term analyses of quota systems. Future studies on e.g. the analysis of quota markets, the calculation of welfare effects of quota systems or on the comparison of quotas with other policy instruments can be improved by taking the possibility of factor under-utilisation into account. Ignoring this effect leads to systematically overestimating shadow prices of production rights. For the Dutch government buying out pig production rights, overestimation of the price of pig production rights leads to budget costs that are too high. Taking under-utilisation into account implies that compensation for production rights should be lower. With tradable quotas, factor under-utilisation implies that farmers are less willing to buy additional pig production rights.

CHAPTER 4

CAPITAL ADJUSTMENT PATTERNS[1]

4.1 Introduction

Farmers operate their business in a dynamic environment. Fluctuating prices, increasing consumer demands for product quality (e.g. with respect to environmental friendly production methods, animal welfare and food safety), technological change and evolving agricultural and environmental policies frequently require adjustment of production and input levels on individual farms. Quantities of variable production factors like animal feed can usually be adjusted easily together with changing production levels. Quantities of labour, capital and land however, are less easy to adjust. Instantaneous adjustment may be impossible or imply (high) costs of adjustment. In the long run, quantities of these quasi-fixed factors can be adjusted at lower costs of adjustment. Understanding the process of adjustment of quasi-fixed factors is important for a number of reasons. First, it shows how farmers reorganise their production in the long run as a reaction to changes in the economic environment, e.g. a decrease in output prices. Second, understanding adjustments in quasi-fixed factors may explain farmers' entry and exit decisions. Third, knowledge about long run adjustment processes at the farm level can be used in economic models to simulate long-term effects of agricultural and environmental policies on individual farms.

The agricultural economics literature has traditionally paid much attention to the explanation of quasi-fixed factor adjustments. Already in the 1950's two theories explaining adjustment of quasi-fixed factors were developed, i.e. Cochrane's (1955) treadmill theory and Johnson's fixed asset theory (1956). Recently, Chavas (1994) reformulated the fixed asset model in a formal model starting from the farmers' long-run objective function. However, empirical applications of both theories have been limited. Starting from the 1980's many agricultural economic studies have applied the adjustment cost framework in order to explain adjustment of quasi-fixed factors (see e.g. Vasavada and Chambers, 1986; Howard and Shumway, 1988; Thijssen, 1996). In these studies it is assumed that a farm incurs a cost in adjusting its stock of quasi-fixed factors, preventing immediate adjustment of the quasi-fixed

---

[1] Paper by Gardebroek, C., submitted for publication to *European Review of Agricultural Economics.*

factors. Examples of such costs are reductions in output due to the restructuring of the production process, administrative costs, search costs etc. The optimisation problem of the farmer then becomes maximising the discounted sum of future profits or minimising the discounted sum of future costs, taking into account changes in the stock of quasi-fixed factors and the costs associated with these changes.

A popular specification of the adjustment cost function is the symmetric quadratic, implying strictly convex adjustment costs over the whole range of adjustment. Convex adjustment costs imply that it is cheaper to spread investments over time than to adjust instantaneously. However, the symmetric quadratic specification has the drawback that it cannot explain zero investments adequately. Mussa (1977) and Abel (1983) showed that the optimal rate of investment is the rate that equates the marginal cost of investment with the marginal value of installed capital. The marginal cost of investment consists of the unit purchase price of capital and the marginal adjustment cost. The latter is zero at zero investment, implying that the marginal value of installed capital equals the unit purchase price of capital at zero investment. Since micro-economic datasets usually contain a large number of zero observations on investment, this implies that a large number of observations would have a marginal value of installed capital exactly equal to the unit purchase price of capital, which is hard to believe. Any deviation of the marginal value of installed capital from the unit purchase price should lead to investment or dis-investment. Considering this large number of zero investments, it is more realistic to have a range of values for the marginal value of installed capital for which investment is zero, which is exactly the idea of fixed asset theory. Another drawback of the symmetric quadratic adjustment cost specification is that it imposes adjustment costs of investment and dis-investment to be symmetric. However, a priori there is no reason to assume that acquiring capital involves the same costs as removing it.

A number of studies have employed more general specifications of the adjustment cost function in order to address these shortcomings. Chang and Stefanou (1988) and Pfann and Palm (1993) allowed adjustment costs for quasi-fixed factors to be asymmetric. Abel and Eberly (1994) combined fixed asset theory and adjustment cost theory in a general model of investment that also accounts for uncertainty. Augmenting the quadratic adjustment cost function with a fixed cost of adjustment that is only incurred if a farm adjusts, introduced a discontinuity in the adjustment cost function at zero investment. Furthermore, they included a difference between the unit purchase and selling price of capital. The number of empirical studies that combine fixed asset theory and adjustment cost theory has been limited thus far. Oude Lansink and Stefanou (1997) estimated a dynamic dual threshold model of investment that is based on the theoretical framework of Abel and Eberly. Pietola and Myers (2000) estimated an extended dynamic dual model including uncertainty. Both studies used farm-level data to estimate the generalised adjustment cost function model.

However, what has not been taken into account in these studies is that farms may differ in the adjustment costs they face for a given investment. The difference between the unit purchase and selling price is not necessarily the same for all farms. Furthermore, reductions in production (internal adjustment costs), costs of acquiring building and environmental licenses necessary for investment, administrative costs and search costs (external adjustment costs) are expected to differ by farm for a given investment. Moreover, Oude Lansink and Stefanou (1997) and Pietola and Myers (2000) use the dual approach in modelling dynamic factor demand. Although this has a number of advantages, i.e. it is flexible with respect to the underlying production structure and adjustment costs function, it allows for interrelated adjustment cost parameters and it is straightforward to generate closed form decision rules, it has a number of drawbacks as well. First, the adjustment cost function is not explicitly specified, so that it is not possible to analyse the structure of the adjustment cost function. Second, most dynamic dual studies are based on static price expectations and therefore subject to the Lucas' critique (1976). Although some progress has been made on incorporating non-static expectations (Luh and Stefanou, 1996; Pietola and Myers, 2000) this usually requires the assessment of expectations outside the model. An alternative primal approach is to derive necessary conditions for an optimum and estimate these optimality conditions directly (see e.g. Pindyck and Rotemberg 1983; Shapiro, 1986). Assuming that farmers form their expectations rationally, i.e. they know the underlying processes specified in the model, unobserved expected values of variables are replaced by their realised counterparts and an expectation error is added to the model. The advantage of this approach is that the adjustment cost function is specified explicitly, which allows for testing various adjustment cost specifications. This yields insight in the structure of the adjustment cost function and the nature of the adjustment process for different capital goods, taking differences in adjustment costs between farms into account.

The objective of this chapter is to model capital adjustments in buildings and machinery for Dutch pig farms taking farm-specific differences in adjustment costs into account. The investment model combines asset fixity and adjustment cost theory in one coherent framework. For the adjustment cost function a flexible specification is used. This flexible specification nests a number of adjustment cost specifications including the quadratic and the linear specification. Moreover, combinations of these specifications are possible, allowing for more flexibility for the adjustment cost function over different regions of adjustment. Different specifications of the adjustment cost function are tested for.

The model is estimated using panel data of specialised Dutch pig farms (breeding, fattening and mixed pig farms) over the period 1980-1996. The Dutch pig sector is an interesting case for studying investment behaviour for two reasons. With the total number of pigs increasing from 10.1 million in 1980 to 13.6 million in 1999 and the number of farms with pigs decreasing from 44 thousand to 16 thousand in the same period, it is clear that the average size of Dutch pig farms has increased rapidly the last two decades (LEI/Statistics Netherlands, 2000: 101). This increase in average size, accompanied by an ongoing specialisation, implied considerable capital investments for individual farms. However, the increasing scale of production on individual farms also led to growing pressure on the environment. Starting in the mid-eighties, the Dutch government implemented a number of policy measures to stop the growth of pig production. Restrictions on expansion were set by means of building and environmental licenses followed by a system of manure production rights. This package of legislation implies that considerable costs had to be made in order to increase production capacity. Part of these costs are typical adjustment costs, e.g. costs involved in acquiring licenses and administrative costs. Therefore, it is expected that pig farmers faced considerable adjustment costs for investment over the period studied, providing a second reason for studying investment of Dutch pig farmers.

The remainder of this chapter is structured as follows. In section 4.2, an inter-temporal profit maximisation model of pig farms is developed. Writing the problem as a dynamic programming problem, first order conditions are derived and combined. Section 4.3 gives the empirical model and estimation method used and the data is described in section 4.4. Section 4.5 discusses the estimation results and conclusions and final remarks are given in section 4.6.

4.2 A generalised investment model

In this section a generalised investment model for Dutch pig farms is developed. This model is an extension of the model in Chavas (1994). Making assumptions on the objective of farmers and the constraints faced in optimising, necessary first-order conditions (f.o.c.'s) for positive, zero and negative investment are derived for buildings and machinery. Next, these f.o.c.'s are solved yielding a set of equality and inequality conditions containing observable variables only.

The objective of pig farmers is assumed to be maximising the expected stream of future cash flows at time t:

$$PV_{ht} = E_{ht}\left[\sum_{j=0}^{\infty} r_{t+j} CF_{ht+j}\right] \tag{4.1}$$

where PV_{ht} is the expected present value for farm h at time t, E_{ht} is the expectations operator conditional on the information available to farm h at time t and r_{t+j} is the real discount rate which is defined as:

$$r_{t+j} = \prod_{i=1}^{j}\left(1 + r_{t+i}\right)^{-1} \qquad \text{and} \qquad r_t = 1$$

where r_{t+i} is the real interest rate. Equation (4.1) is maximised subject to the following set of constraints:

$$CF_{ht}\left(X_{ht}, K_{ht}, Z_{ht}, I_{ht}\right) = p_t F\left(X_{ht}, K_{ht}, Z_{ht}\right) - w_t X_{ht} - p_t^{+} \cdot I_{ht}^{+} + p_t^{-} \cdot I_{ht}^{-} - y\left(I_{ht}\right) \tag{4.2}$$

$$K_{ht} = I_{ht} + \left(1 - d\right) K_{ht-1} \tag{4.3}$$

$$I_{ht} = I_{ht}^{+} - I_{ht}^{-} \tag{4.4}$$

Equation (4.2) defines cash flows for farm h in year t as revenues of production minus variable costs, adjustment costs and total investment expenditure. Total production in year t, represented by the production function *F(.)*, depends on a vector of variable inputs X_{ht}, a vector of quasi-fixed factors, containing buildings and machinery, and a vector of fixed factors Z_{ht}. Output price is p_t and input prices are denoted by a vector w_t. Each period, farmers decide on investment in buildings and machinery. Total investment expenditure consists of the expenditure on new capital goods minus the revenues from capital goods sold. The unit purchase prices of buildings and machinery, given by the vector p_t^{+}, are assumed to be higher than the prices at which used buildings or machinery are sold, p_t^{-}. The difference between the two prices is the part of the unit investment cost that is sunk into the relationship (Chavas, 1994). This price differential is generally referred to as the asset fixity trap (Edwards, 1959). Moreover, it is assumed that when farmers invest, costs in adjusting these quasi-fixed factors are faced. Examples of adjustment costs are learning costs, costs of restructuring the production process, costs associated with building licenses or environmental licenses, the value of time spent on preparing the investment, fees paid to banks in order to get a loan etc. These costs are represented by the adjustment cost function y that depends on the size of gross investments in buildings and machinery in year t, given by the vector $I_{t,h}$. The following basic assumptions on the adjustment cost function are made: y is non-negative, increasing in investment (at an increasing rate in the limit) and it is zero at zero investment.

Equation (4.3) gives the capital accumulation identities, stating that the current stock of a capital good consists of last year's capital stock, corrected for depreciation (d is the depreciation rate), plus current investment in that capital good. Total investment in buildings or machinery is positive investment, I_{ht}^{+}, minus dis-investment, I_{ht}^{-}, as indicated by equation (4.4).

The problem given by the set of equations (4.1)-(4.4) can be considered as a dynamic programming problem with corresponding Bellman equation:

$$PV_t(K_{t-1}) = \max_{x_t, I_t} \left\{ \begin{array}{l} p_t F(X_t, I_t + (1-d)K_{t-1}, Z_t) - w_t X_t - y(I_t) - p_t^{I^+} \cdot I_t^+ + p_t^{I^-} \cdot I_t^- \\ + E_t [r_{t+1} PV_{t+1}(I_t + (1-d)K_{t-1})]; \\ I_t = I_t^+ - I_t^-, \, I_t^+ \geq 0, \, I_t^- \geq 0, \, X_t > 0 \end{array} \right\} \qquad (4.5)$$

where individual farm subscripts h are left out for notational convenience. Note that the present value at time t depends upon the given states of buildings and machinery denoted by the vector K_{t-1}. In period t the control variables I_t are set to optimal levels such that in period $t+1$ the state variables are K_t.

For both investment in buildings and machinery, three regimes are discerned: $I_{it} > 0$, $I_{it} = 0$ and $I_{it} < 0$, where i=1 denotes buildings and i=2 is machinery. The indicator i is added since investment in buildings and machinery are not necessarily in the same regime for a given observation. From the Kuhn-Tucker conditions for $I_{it} \geq 0$ and $I_{it} \leq 0$ the following first-order necessary conditions for investment are derived:

$$I_{it} > 0 \quad \left(I_{it}^{+} > 0\,,\, I_{it}^{-} = 0\right) \qquad p_t \frac{\partial F_t}{\partial K_{it}} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_{it}} \right] = p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} \tag{4.6a}$$

$$I_{it} = 0 \quad \left(I_{it}^{+} = 0\,,\, I_{it}^{-} = 0\right) \qquad p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} \le p_t \frac{\partial F_t}{\partial K_{it}} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_{it}} \right] \le p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} \tag{4.6b}$$

$$I_{it} < 0 \quad \left(I_{it}^{+} = 0\,,\, I_{it}^{-} > 0\right) \qquad p_t \frac{\partial F_t}{\partial K_{it}} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_{it}} \right] = p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} \tag{4.6c}$$

Note that these f.o.c.'s contain the expected discounted dynamic shadow price of period *t+1*, $E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_t} \right]$, which is unobserved. Using the Euler equation approach the expected dynamic shadow price can be substituted out of the model. Examples of the Euler equation approach are found in e.g. Pindyck and Rotemberg (1983), Shapiro (1986) and Chirinko (1993). Differentiating equation (4.5) with respect to K_{t-1} using the envelope theorem yields:

$$\frac{\partial PV_t}{\partial K_{it-1}} = (1-d_i)\left\{ p_t \frac{\partial F_t}{\partial K_{it}} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_{it}} \right] \right\} \tag{4.7}$$

Combining (4.6) and (4.7) gives:

$$I_{it} > 0 \qquad \frac{\partial PV_t}{\partial K_{it-1}} = (1-d_i)\left(p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} \right) \tag{4.8a}$$

$$I_{it} = 0 \qquad (1-d_i)\left(p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} \right) \le \frac{\partial PV_t}{\partial K_{it-1}} \le (1-d_i)\left(p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} \right) \tag{4.8b}$$

$$I_{it} < 0 \qquad \frac{\partial PV_t}{\partial K_{it-1}} = (1-d_i)\left(p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} \right) \tag{4.8c}$$

Using equations (4.8) one period ahead and substituting them into equations (4.6) makes it possible to substitute out the unobservable dynamic shadow price, $\frac{\partial PV_{t+1}}{\partial K_{it}}$, and reduce the problem to a set of conditions comparing marginal costs of (dis-)investment over two subsequent periods:

$$I_{it} > 0,\, I_{it+1} > 0 \qquad E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] = p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \tag{4.9a}$$

$$I_{it} > 0,\, I_{it+1} < 0 \qquad E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] = p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \tag{4.9b}$$

$$I_{it} < 0,\, I_{it+1} > 0 \qquad E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] = p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \tag{4.9c}$$

$$I_{it} < 0,\, I_{it+1} < 0 \qquad E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] = p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \tag{4.9d}$$

$$\begin{aligned} I_{it} = 0,\, I_{it+1} > 0 \qquad & p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \le E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \\ & \le p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \end{aligned} \tag{4.9e}$$

$$\begin{aligned} I_{it} = 0,\, I_{it+1} < 0 \qquad & p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \le E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \\ & \le p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \end{aligned} \tag{4.9f}$$

Note that for cases with $I_{it+1} = 0$ it is not possible to obtain a direct solution, since we cannot substitute (4.8b) into the expressions (4.6). However, rewriting expressions (4.6a)-(4.6c) and taking expectations of inequality (4.8b) one period ahead, the following necessary conditions can be derived for these regimes:

$$\begin{aligned} I_{it} > 0,\, I_{it+1} = 0 \qquad & p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \le E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \\ & p_{it}^{I^+} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \ge E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \end{aligned} \tag{4.9g}$$

$$\begin{aligned} I_{it} < 0,\, I_{it+1} = 0 \qquad & p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \le E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \\ & p_{it}^{I^-} + \frac{\partial y_t}{\partial I_{it}} - p_t \frac{\partial F_t}{\partial K_{it}} \ge E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-} + \frac{\partial y_{t+1}}{\partial I_{it+1}} \right)\right] \end{aligned} \tag{4.9h}$$

$$I_{it}=0\,,I_{it+1}=0 \qquad p_{it}^{I^-}+\frac{\partial y_t}{\partial I_{it}}-p_t\frac{\partial F_t}{\partial K_{it}}\le E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^+}+\frac{\partial y_{t+1}}{\partial I_{it+1}}\right)\right]$$

$$p_{it}^{I^+}+\frac{\partial y_t}{\partial I_{it}}-p_t\frac{\partial F_t}{\partial K_{it}}\ge E\left[r_{t+1}(1-d_i)\left(p_{it+1}^{I^-}+\frac{\partial y_{t+1}}{\partial I_{it+1}}\right)\right] \qquad (4.9i)$$

These combined first order necessary conditions have the following interpretation. For the regimes with non-zero investment in two subsequent periods, the right hand side sums up the marginal costs and marginal benefits of investing (dis-investing) in period *t*. The marginal costs consist of the unit purchase (selling) price of capital and the marginal adjustment cost. The marginal benefit consists of the value of marginal product in year *t*. Since this benefit can be considered as a negative cost, it is subtracted from the sum of marginal costs. Note that in the case of dis-investment, the selling price is actually a benefit and the marginal product, which becomes negative, is an additional cost. The left-hand side represents the expected discounted sum of marginal costs of investment (dis-investment) in period *t+1*. So, optimal investment in period *t* requires that marginal costs of investment are equated in periods *t* and *t+1*. In other words, farmers invest in period *t* until the marginal cost of investment equals the expected discounted marginal cost of investment in period *t+1*. In this comparison it is taken into account that investment in period *t* implies a marginal benefit consisting of the value of marginal product in period *t*, which is not obtained when investment is postponed to period *t+1*. Conditions (4.9e) and (4.9f) imply that farmers neither invest nor dis-invest in period *t* when marginal costs of investment in period *t* is higher respectively lower than marginal costs of investment in period *t+1*. The reverse explanation holds for the regimes with zero investment in period *t+1*, as given by conditions (4.9g) and (4.9h). For the regime with zero investment in both periods, the conditions in (4.9i) state that dis-investing today is less attractive (higher marginal costs) than investing tomorrow but also that investing today is less attractive than dis-investing tomorrow.

4.3 Empirical model and estimation

In the previous section a set of optimality conditions for a generalised investment model are given. Since the optimality conditions with either I_t=0 or I_{t+1}=0 are inequality conditions, they cannot be used in estimation. In principle, estimation could be based on conditions

(4.9a)-(4.9d). However, since the number of observations with negative investments in buildings or machinery is small[2], and there are no price indices for the unit selling price of used buildings and machinery available, only equation (4.9a) is used in estimation. In order to estimate equation (4.9a) for buildings and machinery, a number of steps are taken. First, functional forms are specified for the production function and the adjustment cost function. From these functions expressions for the marginal products and marginal adjustment costs of buildings and machinery are derived and substituted in equation (4.9a). Furthermore, assumptions are made on the expectation formation process. This section concludes with a discussion on the estimation method used.

Production function

For the production function a quadratic functional form with two variable inputs (feed and other variable inputs), two quasi-fixed capital goods (buildings and machinery) and three fixed factors (family labour, land and technological change) is used:

$$F(x_{ht}) = a_{0h} + \sum_{i=1}^{7} a_i x_{iht} + \tfrac{1}{2} \sum_{i=1}^{7} \sum_{j=1}^{7} a_{ij} x_{iht} x_{jht} \qquad (4.10)$$

where x_{iht} denotes respectively buildings (i=1), machinery (i=2), feed input (i=3), other variable input (i=4), labour (i=5), land (i=6) and technological change (i=7). Furthermore, α_{0h} is a farm-specific effect in the production function. Differentiating equation (4.10) with respect to buildings or machinery yields the marginal product to be used in (4.9a).

Adjustment cost function

For the adjustment cost function the following flexible specification is used for investment in buildings and machinery:

$$y\,(I_{iht}) = b_{i1h} I_{iht} + \tfrac{1}{2} b_{i2} I_{iht}^2 + \tfrac{1}{3} b_{i3} I_{iht}^3 \qquad b_{i1h} \geq 0 \qquad i = 1,2 \qquad (4.11)$$

[2] In the dataset used, both buildings and machinery have 9 observations with negative investment. An explanation for these particularly low numbers is that farmers who sell their buildings or machinery are likely to quit farming and therefore leave the dataset.

where b_{i1h} is a farm-specific linear adjustment cost term. Note that since only equation (4.9a) is estimated, adjustment costs for negative investments are not considered. However, for negative investments a similar specification could be used, $b_{i4h}I_{iht} + \frac{1}{2}b_{i5}I_{iht}^2 + \frac{1}{3}b_{i6}I_{iht}^3$, with $b_{i4h} \leq 0$.

This specification not only nests a number of well-known specifications (linear, convex quadratic, asymmetric adjustment costs; for an overview see Hamermesh and Pfann, 1996), it also has a number of desirable properties. First, the linear term $b_{i1h} \cdot I_{iht}$ implies a discontinuity in marginal adjustment costs at zero investment, since marginal adjustment costs for negative investments contain the term b_{i4h}, which is smaller than or equal to zero, instead of b_{i1h}, which is larger than or equal to zero. This discontinuity in adjustment costs provides an additional explanation for observed asset fixity (Hsu and Chang, 1990) besides the price difference between unit purchase and selling prices. Allowing this linear term to be farm-specific accounts for differences in adjustment costs between farms. Farms may have different unit purchase prices of capital goods, different costs of building and environmental licenses, different administrative or search costs or different production losses due to restructuring the of the production process.

Whited (1998) proposed to add cubic and higher-order terms to the adjustment cost function. Using data on U.S. manufacturing firms over the period 1982-1987, he found that a quadratic specification resulted in negative adjustment cost, whereas the flexible specification restored the positive relation between investment and adjustment costs. Moreover, specification testing did not reject inclusion of higher-order terms. Adding a cubic term also allows for a wider variety of adjustment cost functions. If $b_{i2} + 2b_{i3}I_{iht} > 0$ then the adjustment cost function is convex in investment. Increasing marginal investment costs provide a rationale for investment spreading over time. It may be cheaper to spread an investment over two or more periods in order to reduce adjustment costs than to invest immediately. This is the basic investment theory behind convex quadratic adjustment cost functions.

However, Rothschild (1971) questioned the necessity of strictly convex adjustment costs over the whole range of investment. Although it seems to make sense for large investments to be split up in sequencing projects in order to reduce costs, it does not for small investments. In the words of Rothschild: *"Convex cost of adjustment functions may help to explain why Rome was not built in a day. However, there is no clear saving and may be some loss to spreading the work of installing a button on a shirt over several weeks."* For farm investment a similar reasoning holds. Building a new barn in one week may be a very expensive enterprise. Constructors have to reallocate a large part of their capacity into this single project and therefore will charge extra fees. Also more expensive building techniques may have to be used. Therefore, it is cheaper to spread out building over time and stick to normal building practice. However, for buying new farm machinery or a microcomputer there seems to be no gain in spreading the investment over time. Once it is decided to invest in these capital goods, it is usually done instantaneously. In these cases, spreading over time may be impossible anyhow. So, although for large investments convexity of the adjustment cost function may be a plausible assumption, for small investments it is not. Therefore, an adjustment cost function with an initial non-convex part followed by a strictly convex part is more appropriate (Rothschild, 1971; Nickell, 1978: 37). The non-convex part ensures immediate jumps for small investments. In this range it is cheaper to adjust quickly instead of spreading out an investment over more than one period due to initial economies of scale in adjusting the capital stock. In order to allow for initial non-convexities in the adjustment cost function, b_{i2} has to be negative and b_{i1h} and b_{i3} positive. So, inclusion of the cubic term allows for testing for such non-convexities. However, if such non-convexities exist, then optimally behaving farmers should always invest more than investments in the non-convex range. Davidson and Harris (1981) show that an investment in the concave range would never be optimal, due to decreasing average adjustment costs. This also follows from equation (4.8a). If this equality holds in the concave range it is always optimal to invest more, since then marginal adjustment costs will be lower than the shadow price of capital. Investment would go on until the equality holds in the convex range. So, in theory an initial concave part can exist, but no observations will be in this range if farmers are unrestricted in choosing the size of the investment. However, in practice there may be all kinds of constraints (e.g. credit constraints, regulatory constraints) keeping farmers from investing an optimal amount in the convex region of the adjustment cost function.

Expectations formation

Another prerequisite for equation (4.9a) to be estimated is that assumptions on the expectation formation of period $t+1$ variables are made. Recognising that farmers use current and historical information in forming expectations, rational expectations are assumed (for a thorough discussion see Pesaran, 1987). Rational expectations imply that farmers know the system estimated. Although this seems to be a too strong statement of farmers' capabilities in forming expectations, at least it assumes that farmers know the relations between the model variables. Naïve, adaptive or quasi-rational expectations are formed for each variable independently, without recognising that levels of model variables affect the levels of others model variables.

Assuming rational expectations, expected values of time $t+1$ variables are replaced by their realised values and an error term e_{it+1}, capturing the differences between the expected and the realised values of variables in $t+1$, is added to equation (4.9a). Using the first order derivative of (4.10) with respect to capital and the first order derivative of (4.11) with respect to investment and substituting them into (4.9a), yields the following expression after some rewriting:

$$\begin{aligned}(1-d_i)r_{t+1}\left(b_{i1h}+b_{i2}I_{iht+1}+b_{i3}I_{iht+1}^2+p_{it+1}^{I^+}\right)-b_{i1h}-b_{i2}I_{iht}-b_{i3}I_{iht}^2-p_{it}^{I^+}\\ +p_t\left(a_i+\sum_{j=1}^{7}a_{ij}x_{jht}\right)=e_{iht+1}\quad for\ i=1,2\end{aligned} \tag{4.12}$$

Properties of these errors are that $E(e_{iht+1})=0$, $E(e_{iht+1}^2)=s_{iht+1}^2$ and that e_{iht+1} is uncorrelated with any time t information. However, although expectations on period $t+1$ variables are orthogonal to the expectation errors since they are a function of period t variables, their realised $t+1$ values are not. Therefore, OLS estimates will be inconsistent and an instrumental variable estimator is necessary. In principle any period t variable can be used as an instrument. The Generalised Method of Moments (GMM; Mátyás, 1999) is used to estimate (4.12) since it directly uses the above orthogonality conditions in the estimation procedure. Period t information is used in a vector of instruments z_{iht} and the moment condition is rewritten as $E_{ht}(z_{iht}\cdot e_{iht+1})=0$, where e_{iht+1} is defined in (4.12).

Panel data

The availability of panel data allows for specifying the farm-specific linear adjustment cost terms for buildings and machinery. Besides this farm-specific linear adjustment cost parameter b_{i1h}, a farm-specific effect m_{ih} is added to equation (4.12). This farm-specific effect represents other unobserved time-invariant farm characteristics (e.g. management or farm-specific expectation errors). Note that both farm-specific parameters cannot be distinguished from each other. Equation (4.12) is estimated in first differences in order to avoid estimating all the farm-specific parameters. Taking first-differences implies that the choice of instruments that can be used is limited. Period *t* variables are now correlated with the first-differenced expectation errors and are therefore no longer valid instruments. The moment condition now becomes $E(z_{iht-1}\Delta e_{iht+1})=0$ where Δ denotes first-differences. Valid instruments in GMM estimation with panel data consist of period *t-1* and earlier values of model variables (Arellano and Bond, 1991). The instrument set consists of two and more periods lagged values of investment and investment squared in buildings or machinery, the purchase price of buildings or machinery, the output price, the prices of feed and other variable input and quantities of capital, family labour and land and technological change.

Sample selection bias

As discussed before, only the inter-temporal optimality condition for positive investment in both periods *t* and *t+1*, equation (4.9a), is estimated. However, the model parameters are also valid for the zero investment regime (and also partly for the negative investment regime if this would be considered). Therefore, using only observations with positive investments may induce a sample selection bias. In order to correct for this sample selection problem estimation is conditioned on the event $D_{iht+1}=\Gamma(I_{iht+1}\cdot I_{iht}\neq 0)=1$, where $\Gamma(.)$ is the indicator function, which takes value one if the condition is true and zero otherwise (Alonso-Borrego, 1998). The corresponding sample selection rule is defined as:

$$\begin{aligned} D_{iht+1}&=1 \quad \text{if } D^{*}_{iht+1}=gZ_{iht-1}+x_{iht+1}>0\\ D_{iht+1}&=0 \quad \text{if } D^{*}_{iht+1}=gZ_{iht-1}+x_{iht+1}\leq 0 \end{aligned} \tag{4.13}$$

where D_{iht+1} is a latent variable, γ a vector of parameters and x_{iht+1} the residual of the selection equation. Under this conditioning event, the population moment condition is partitioned as:

$$\begin{aligned} E(z_{it-1}\Delta e_{it+1}) &= E(z_{it-1}\Delta e_{it+1}\mid D_{it+1}=1)\cdot \Pr(D_{it+1}=1)\\ &\quad + E(z_{it-1}\Delta e_{it+1}\mid D_{it+1}=0)\cdot \Pr(D_{it+1}=0)=0 \end{aligned} \tag{4.14}$$

From the partitioning it follows that the moment condition, conditional on D_{iht+1}=1 differs from the population moment condition and in general cannot expected to be zero since it only represents part of the distribution of expectation errors. This is further explained by considering equation (4.9a). Using the above partitioning of the population moment condition (4.14), the conditional moment condition is rewritten as:

$$E\left(z_{iht-1}\Delta e_{iht+1} \mid D_{iht+1}=1\right)=-E\left(z_{iht-1}\Delta e_{iht+1} \mid D_{iht+1}=0\right)\frac{\Pr\left(D_{iht+1}=0\right)}{\Pr\left(D_{iht+1}=1\right)}=$$
$$-z_{iht-1}E\left(\Delta e_{iht+1} \mid x_{iht+1}\leq -gZ_{iht-1}\right)\frac{\Pr\left(x_{iht+1}\leq -gZ_{iht-1}\right)}{1-\Pr\left(x_{iht+1}\leq -gZ_{iht-1}\right)}=-z_{iht-1}s\ \frac{f\left(-gZ_{iht-1}\right)}{1-\Phi\left(-gZ_{iht-1}\right)} \quad (4.15)$$

where s is the covariance between Δe_{iht+1} and x_{iht+1} (normalised by the variance of x_{iht+1}), $f\left(-gZ_{iht-1}\right)$ is a normal density function and $\Phi\left(-gZ_{iht-1}\right)$ is a normal distribution function. The ratio $f\left(-gZ_{iht-1}\right)/\left(1-\Phi\left(-gZ_{iht-1}\right)\right)$ is the Inverse Mill's ratio, which is denoted as l_{iht+1}. Correcting for sample selection bias, the following moment condition is assumed to hold:

$$E\left(z_{iht-1}\left(\Delta e_{iht+1}-s\,l_{iht+1}\right) \mid D_{iht+1}=1\right)=0 \quad (4.16)$$

Since the expectation taken is conditional on the information set of period *t-1*, and the explanatory variables in the selection rule (4.13) should be in the information set, it follows that the Inverse Mill's ratio is also based on period *t-1* information. Note that this sample selection correction does not take the panel nature of the data into account. That would require a panel probit estimation for sample selection. However, a panel probit model with fixed effects cannot be estimated (Maddala, 1987).

Substituting the l_{it+1} by consistent estimates based on reduced-form probit estimates, equations (4.16) are estimated using GMM, where e_{it+1} is defined in equation (4.12). Define $f_{ht}\left(y_h,q\right)=z_{ht-1}\left(\Delta e_{ht+1}-s\,l_{ht+1}\right)$, where y_h is a vector of all model variables and instruments in (4.16) for farm h and q is the vector of parameters to be estimated, and define $f\left(y,q\right)=\left[\frac{1}{H}\sum_{h=1}^{H} f_{h1}\left(y_h,q\right),\ldots,\frac{1}{H}\sum_{h=1}^{H} f_{hT-1}\left(y_h,q\right)\right]$, then $\hat{q}_{GMM}$ is the estimator that minimises the objective function:

$$Q(q)=f\left(y,q\right)' V^{-1} f\left(y,q\right) \quad (4.17)$$

where V^{-1} is a weighting matrix. The GMM estimator is particularly apt for equations like (4.16). It can handle non-linear equations and allows for heteroskedastic errors. Furthermore, distributional assumptions on the data (e.g. normality) are not necessary (Ogaki, 1999). For an overview of GMM estimation see Mátyás (1999).

4.4 Data

Data on specialised pig farms covering the period 1980-1996 are obtained from a stratified sample of Dutch farms keeping accounts on behalf of the Dutch Agricultural Economics Research Institute (LEI) farm accounting system. Farms were selected if the share of pig output in total output exceeds 80%. The farms remain in the panel for about five to seven years, so the panel is unbalanced.

Investment for both capital goods is defined as the sum of purchases and sales. The marginal products used in the equations estimated contain the quasi-fixed factors buildings and machinery, two variable inputs, feed and other variable inputs, and the fixed factors family labour, land and technological change. Implicit quantities for buildings, machinery, feed and other variable inputs are obtained by dividing their total values by their respective (Tornquist) price indices. These implicit quantities are measured at constant 1980 prices. Total farm family labour is measured in hours, land is measured in hectares and for technical change a time trend is used. The netput price for output is a Tornquist price index calculated with prices obtained from LEI/Statistics Netherlands (several years). The discount factor and the depreciation rates are considered constant in estimation. The discount factor used is the average over the estimation period, 0.95 and is based on the real interest rate. The depreciation rate for buildings is assumed to be 4% and for machinery 10%.

Taking first differences and using twice-lagged values of endogenous variables implies that only farms with three or more observations can be used in estimation and that data of the first two years for each farm can only be used as instruments. Removing farms with one or two observations and the few observations with negative observations on investment results in a data set with 1430 observations on 279 farms. Basic statistics of the data are given in appendix III.

These observations are used to estimate the reduced form probit models necessary for calculating the Inverse Mill’s ratios. Note that in estimation of equations (4.12) for buildings and machinery only observations with two subsequent observations on investment can be used. Since in the dataset the number of zero observations for buildings differs from that for machinery, the optimality conditions (4.12) are estimated separately for buildings and machinery. This implies that in the estimation of equation (4.12) for buildings only 263 observations are used, whereas in the estimation for machinery 579 observations are used.

4.5 Results

This section presents the results of estimating equation (4.12) for buildings and machinery. First, reduced form probit estimates are presented that are used to obtain the Inverse Mill's Ratios necessary for sample selection bias correction in equations (4.12). Second, parameter estimates for equations (4.12) are given and discussed.

Reduced probit model estimates for calculating Mill's ratio

In order to control for sample selection bias, arising from using only positive observations in the estimation of the inter-temporal optimality condition (4.12), first a probit reduced form is estimated. With this probit model the occurrence of two subsequent observations on positive investment, $D_{iht+1} = 1$, is explained by two, three and four period lagged values of the model variables. Those variables are also used as instruments in the final GMM estimation. Furthermore, an additional set of two period lagged variables was added including *age*, the age of the farmer, a dummy variable *succ*, indicating whether a successor is present, the debt-asset ratio denoted as *dar*, the increase in equity capital *eqc*, the total amount of interest paid, *int*, and the income of the farmer, *inc*. Whereas the first two variables are related to the personal situation of the farmer, the latter variables give an indication of the financial situation of the farm. Table III.2 in appendix III gives the probit estimates for buildings and machinery.

In the probit estimation for buildings, 12 parameters are significantly different from zero at the 10% level (9 at the 5% level). From the two period lagged variables gross investments, the quantities of buildings, labour and land, the age of the farmer, the increase in equity capital, the total amount of interest paid and the income of the farmer are significant. Furthermore, the quantity of buildings, the unit purchase price of buildings, the output price and technical change, all three periods lagged are significant. Some of these parameters have the expected sign, e.g. the probability of two consecutive investments decreases with age (older farmers are expected to invest less frequent) but increases with an increase in the income of the farmer two periods lagged (farmers with larger positive receipts in the past are expected to invest more frequent). Furthermore, it appears that investment in buildings two periods ago also has a positive impact on investing in buildings in the future. For machinery 10 variables have parameters significantly different from zero at the 10% level (7 at the 5% level): investment in machinery, the output price, quantities of labour and land, the debt-asset ratio, income of the farmer and the increase in equity capital all two periods lagged, the unit purchase price and the output price three periods lagged and labour four periods lagged. Again, investment two periods lagged and the income of the farmers have a positive impact on two consecutive investments in periods *t* and *t+1*. The signs of the parameters for the debt-asset ratio and the increase in equity capital two periods lagged are opposite to what was expected. Note however that care should be taken in interpretation since two and more periods lagged variables are used to predict the probabilities of consecutive investments in periods *t* and *t+1*. What also should be noted is that for both probit models there is a wide divergence between McFadden's R^2 (respectively 0.09 and 0.17) and Count R^2 (respectively 0.71 and 0.73). Apparently, a probit model with only a constant would also have made a large number of correct predictions and the explanatory variables do not add much to the model.

Euler equation parameter estimates for buildings

Using these probit parameter estimates, Inverse Mill's ratios are calculated for buildings and machinery for observations with positive investment in two consecutive periods and included in the Euler equations as additional regressor. Parameter estimates for the Euler equation of buildings with the flexible adjustment cost function are given in the first column of table 4.1.

Table 4.1 Euler equation parameter estimates for investment in buildings (standard errors in parentheses)

Parameter	Flexible a.c.f.		Quadratic a.c.f.		Farm spec. linear a.c.f.	
α_1	-0.021	(0.056)	-0.056	(0.054)	-0.052	(0.054)
α_{11}	-0.010	(0.004)**	-0.007	(0.004)**	-0.005	(0.003)
α_{12}	0.049	(0.025)*	0.040	(0.025)	0.048	(0.024)**
α_{13}	-0.006	(0.008)	$0.3*10^{-3}$	(0.007)	0.001	(0.007)
α_{14}	0.014	(0.013)	-0.003	(0.011)	-0.007	(0.011)
α_{15}	$-0.1*10^{-3}$	(0.009)	0.010	(0.008)	0.007	(0.008)
α_{16}	-0.002	(0.002)	-0.002	(0.002)	-0.002	(0.002)
α_{17}	0.005	(0.004)	0.004	(0.004)	0.004	(0.004)
β_{12}	0.012	(0.005)**	0.003	(0.003)		
β_{13}	$-0.8*10^{-3}$	$(0.4*10^{-3})$**				
σ	-0.004	(0.004)	-0.003	(0.004)	-0.002	(0.004)
J-statistic	21.88		26.72		28.22	
Degrees of freedom	22		23		24	
χ^2 test of exclusion			4.84		6.34	
Degrees of freedom			1		2	

** Significantly different from zero at the 5% level
* Significantly different from zero at the 10% level

For this model only 3 parameters are significantly different from zero at the 5% level. However, the model specification was not rejected in the test for over-identifying restrictions

(Hall, 1999). With 33 instruments, obtained from the 11 model variables lagged two, three and four periods, and 11 parameters to be estimated, there are 22 degrees of freedom. The *J*-test statistic of 21.88 is lower than the critical value of 33.93 (c^2 distribution) indicating that the over-identifying restriction are not rejected.

The quadratic and cubic adjustment cost parameters, which are both significantly different from zero, indicate that the adjustment cost function for buildings is initially convex, but for investments larger than 781 thousand guilders it becomes concave. Although this suggests that for large investments it is not attractive to spread out the investment, it should be noted that in the original dataset only 6 out of 1430 observations have investments in buildings larger than 780 thousand guilders. In other words, the adjustment cost function is convex for 99.6% of the observations. The number of observations in this range is just too small for estimation. So it can be concluded that marginal adjustment costs are positive and increasing in the size of investment, but at a decreasing rate.

The model with the flexible adjustment cost specification was tested against a model with a quadratic adjustment cost function using a test of parameter exclusion (Hall, 1999). Using the weighting matrix from the generalised model, a model with a quadratic adjustment cost function was estimated (column two in table 4.1). Since the test statistic of 4.84 exceeds the critical value $c^2_{1;0.95} = 3.84$, the null hypothesis that b_{13}=0 is rejected. So, the flexible adjustment cost function is favoured over the quadratic one in this case. The quadratic specification also leads to an adjustment cost parameter b_{12} that is not significantly different from zero. For a general test of non-linear adjustment costs, the flexible model was tested against a model that only includes farm-specific linear parameters. Now the null hypothesis that both b_2 and b_3 are equal to zero is rejected with a test statistic of 6.35 exceeding the critical value $c^2_{2;0.95} = 5.99$. So, it can be concluded that non-linear adjustment costs are important in explaining gross investment in buildings.

The parameters a_{ij} indicate the effects of variables on the value marginal product of buildings in the Euler equation (4.12). The higher this value, the more attractive it is to invest in period *t*. The marginal value product of buildings is increasing in machinery (parameter significant at 10% level), feed input and technological change (both not significant). It is decreasing in output price (not significant), buildings (significant at 10% level), labour and land (both not significant). A large stock of machinery makes it more attractive to invest in buildings, whereas a large stock of buildings has a negative impact on the value marginal product of an additional unit of buildings. The negative parameter a_{33} also indicates that the production function is concave in buildings. Note that the parameter for the Inverse Mill's ratio is not significantly different from zero, so sample selection bias was not present. This implies that we could have estimated the model using the subsample of positive observations without correcting for selection bias. Apparently, the distribution for the expectation errors does not differ for the subsample of positive observations from the total sample.

In the flexible adjustment cost function (4.11), farm-specific linear adjustment cost terms were added. The inclusion of farm-specific effects in the Euler equation (4.12) prevents calculation of the farm-specific linear adjustment cost parameters. Although the farm-specific linear adjustment cost parameters b_{i1h} and farm-specific effects m_{ih} cannot be separated, it can be tested whether there are joint farm-specific parameters h_{ih} (=b_{i1h}+m_{ih}) present. If this test indicates that there are no joint farm-specific parameters h_{ih}, equation (4.12) can be estimated in levels and an average linear adjustment cost parameter can be estimated. Holtz-Eakin (1988) developed a test for the presence of farm-specific constants in a dynamic model based on the moments used in estimation. If the null hypothesis of no joint farm-specific effects holds, he showed that besides the moments $E\left(z_{iht-1}\Delta e_{iht+1}\right)=0$, additional moments $E\left(z_{iht-1}e_{iht}\right)=0$ can be used in estimation. If there are no joint farm-specific effects, addition of the latter moments in estimation does not lead to significant increase in the *J*-test statistic in estimation. However, if there are joint farm-specific parameters then the latter moments are invalid and a significant increase in the *J*-test statistic is observed. The test-statistic is the difference in observed *J*-test statistics of a restricted and an unrestricted model, which is distributed as c_n^2, where n is the difference in over-identifying restrictions (see also Hall, 1999). Estimation of the model with the additional moment conditions gives a difference in *J*-test statistics of 71.92, which is larger than the critical value of $c^2_{11;0.95}=19.68$, indicating that the null hypothesis of no joint farm-specific parameters is rejected.

Euler equation parameter estimates for machinery

Parameter estimates for the Euler equation of machinery are given in the first column of table 4.2. In the Euler equation for machinery only the parameter for machinery is significantly different from zero at the 5% level. Moreover, the overidentifying restrictions test indicates that the Euler equation as specified in (4.12) does not hold for machinery. The *J*-test statistic of 39.35 exceeds the critical value of $c^{2}_{22;0.95} = 33.93$, indicating that the null hypothesis that the overidentifying restrictions are equal to zero is rejected.

Table 4.2 Euler equation parameter estimates for investment in machinery (standard errors in parentheses)

Parameter	Generalized a.c.f.		Quadratic a.c.f.		Farm spec. linear a.c.f.	
α_2	-0.214	(0.476)	-0.151	(0.461)	-0.143	(0.461)
α_{12}	0.055	(0.041)	0.055	(0.041)	0.052	(0.041)
α_{22}	-0.328	(0.143)**	-0.327	(0.143)**	-0.280	(0.087)**
α_{23}	-0.049	(0.086)	-0.060	(0.083)	-0.066	(0.082)
α_{24}	0.004	(0.137)	-0.005	(0.136)	0.005	(0.135)
α_{25}	0.063	(0.100)	0.051	(0.097)	0.044	(0.096)
α_{26}	0.011	(0.014)	0.013	(0.014)	0.011	(0.013)
α_{27}	0.005	(0.004)	0.009	(0.037)	0.012	(0.036)
β_{22}	0.124	(0.184)	0.055	(0.132)		
β_{23}	-0.068	(0.127)				
σ	-0.002	(0.065)	0.003	(0.064)	0.009	(0.063)
J-statistic	39.35		39.64		39.82	
Degrees of freedom	22		23		24	
χ^2 test of exclusion			0.29		0.47	
Degrees of freedom			1		2	

** Significantly different from zero at the 5% level

Furthermore, although the adjustment cost parameters suggest a similar pattern as observed for buildings (convex, but convexity decreasing in size of investment), both adjustment cost parameters are not significantly different from zero. Using a quadratic specification or leaving out non-linear adjustment cost parameters does not provide an improvement in the model. The *J*-test statistic is respectively 39.64 and 39.82, in both cases leading to the rejection of the model. Comparing the flexible adjustment cost specification for machinery with a quadratic specification (column two in table four) and applying a parameter exclusion test as described before leads to non-rejection of the null hypothesis that b_3 is zero (test statistic of 0.29 is smaller than the critical value $c^{2}_{1;0.95} = 3.84$). Moreover, testing the hypothesis that both b_2 and b_3 are equal to zero also leads to non-rejection of the null hypothesis (test statistic of 0.47 is smaller than critical value $c^{2}_{2;0.95} = 5.99$). The rejection of the model specification that was found by the *J*-test and the rejection of the quadratic and cubic adjustment cost parameters indicates that investment in machinery is not appropriately explained by the model used in this study. An explanation could be that machinery is not quasi-fixed and that it should be considered as variable. In that case adjustment costs are not important in the decision to buy new machinery and inter-temporal equating of adjustment cost, as implied by the optimality conditions in the model, does not take place. Other explanations for the rejection of the model specification are missing variables in the model or invalidity of the rational expectations hypothesis. Based on the *J*-test, Thijssen (1996) rejected the rational expectations hypothesis in a model of aggregate capital investment for Dutch dairy farming.

Finally, it should be noted that, as before, the farm-specific linear adjustment cost parameters cannot be calculated due to the presence of farm-specific effects in the Euler equation. The test for joint farm-specific parameters has a test-statistic of 93.04, which is much larger than the critical value of $c^2_{11;0.95} = 19.68$, indicating again that the null hypothesis of no farm-specific effects is rejected. It should be noted however, that this test and also the test for parameter exclusion (comparing the different adjustment cost function specifications) are difficult to interpret since the original model is rejected. Finally, note that also for machinery the parameter for the Inverse Mill's ratio was not significant, indicating that sample selection bias was not present and therefore no correction was required.

4.6 Conclusions and discussion

In this chapter a generalised investment model for Dutch pig farmers was specified and estimated. The model combines fixed asset theory and adjustment cost theory in one framework. As opposed to adjustment cost studies that assume adjustment costs to be symmetric and convex the model in this chapter provides an explanation for the zero observations in micro-economic datasets. Recognising that farmers face different adjustment costs for a given investments an adjustment cost function with a farm-specific intercept was assumed. Furthermore, a flexible adjustment cost specification including a quadratic and a cubic term was specified to allow for a variety of adjustment cost functions. The optimality conditions that were obtained using the Euler equation method were estimated separately for buildings and machinery using GMM.

The estimation results show that the optimality condition was not rejected for buildings, whereas for machinery it was rejected. This indicates that for buildings farmers equate marginal adjustment costs of investment in period *t* with the expected marginal adjustment costs in period *t+1*, where the expectations are formed rationally. Having rational expectations on the marginal adjustment costs in period *t+1*, indicates that farmers know how much they invest and what the unit price of buildings is in the next period, up to an expectation error. This finding also implies that adjustment costs are important in deciding how much to invest in buildings.

For machinery the optimality condition was rejected. This may indicate that important variables are missing in the model (e.g. financial variables), that expectations on marginal adjustment costs are not formed rationally or simply that levels of machinery investments are not optimal. Rejection of the model for machinery makes it difficult to indicate the importance of adjustment costs for machinery. Non-linear adjustment costs parameters were not significantly different from zero and were also jointly rejected. However, the validity of these tests is doubtful given the rejection of the original model.

In order to explain zero investments a price differential between the unit purchase price and the selling price was specified in the theoretical model. In the empirical model, farm-specific linear adjustment cost parameters, reflecting differences in linear adjustment costs for farms, were added. These farm-specific parameters could not be separated from other farm-specific effects. Testing indicates that joint farm-specific parameters were present, but their interpretation is not possible. So, farm-specific adjustment cost thresholds can be taken into account in estimation, but the thresholds cannot be obtained. This is rather disturbing if one is interested in whether or not these thresholds for individual pig farms have increased over time, e.g. due to stricter environmental policies. Furthermore, since the linear adjustment cost terms are not known, one can also not calculate adjustment costs.

CHAPTER 5

THE IMPACT OF MANURE PRODUCTION RIGHTS ON CAPITAL INVESTMENT[1]

5.1 Introduction

Since the 1950's the Dutch pig sector has witnessed a rapid growth. In this period the number of pigs rose from around 2 million in 1950 to about 16 million in the mid-nineties. What also grew rapidly was a surplus of manure produced by this increasing number of pigs. In order to curb this manure surplus, the Dutch government implemented a number of environmental policies in the 1980's and 1990's. During the first period of legislation, which lasted from 1984 to 1986, expansion of production was directly restricted by a number of prohibitive rules. However, due to a large use of exceptional dispositions and a possibly weak control system this law did not achieve its objectives. A second period of agri-environmental legislation began in 1987 with the introduction of a system of non-tradable manure production rights. In 1994 legislation was revised and the manure production rights became tradable. Given the close technical relation between the amount of manure produced (total of manure production rights) and the total production level, restrictions on manure production also implied an (indirect) constraint on pig production.

An argument often brought forward against quantitative restrictions on production (e.g. supply quota) is that they hamper structural development. Since farmers cannot expand their farm business, expansionary investments are not profitable and the total amount of investments is reduced. A consequence of lower investments is that the speed of innovation is reduced, deteriorating the long-run productivity of the sector (Richards and Jeffrey, 1997). Concern about reduced investments was one of the arguments for the Dutch government to make manure production rights tradable in 1994, since reduced investments also implied that investments that contributed to solving the manure problem were reduced (LNV, 1996). With tradable manure production rights, farms with high marginal profits buy additional manure production rights from farms with low marginal profits, allowing the former to expand their (manure) production.

---

[1] Paper by Gardebroek, C., submitted for publication to *American Journal of Agricultural Economics.*

Whether output was restricted by the system of manure production rights in the period 1987-1996 is uncertain. Although the growth in pig numbers was halted and investment was somewhat lower than before, it is not well understood whether farms were output constrained or not. The quantity of manure production rights was allotted on the basis of historical production levels which farmers had to indicate themselves. Farmers may have come up with numbers based on maximum production capacity instead of historical production levels, thus creating future possibilities for expansion of production (Frouws, 1994). Furthermore, the decrease in investment may have had other causes. Low output prices in this period may have reduced expected gains from investment or deteriorated the financial situation of farmers. Besides doubts on the constraining effects of the manure production rights it is also not clear whether these constraints were alleviated when the manure production rights became tradable in 1994.

The objective of this chapter is to test whether manure production rights constrained capital investment in the Dutch pig sector over the period 1987-1996 through an indirect constraint on production. In order to address this research question an inter-temporal model of investment is developed. It is assumed that farmers maximise the expected sum of annual cash flows. Cash flows are defined as revenues of production minus variable costs and the costs of investment. The latter consists of the investment expenditure and adjustment costs. In the basic model it is assumed that production is unconstrained. For the period 1987-1996, in which manure production rights may have limited manure production on individual farms, the model is augmented by a (potentially binding) constraint on pig production. Whether this constraint was indeed binding is tested for empirically. Note that investment decisions on manure production rights in the period 1994-1996 are not modelled explicitly. Only the constraining effect of the amount of manure production rights on farm investment is taken into account.

From the inter-temporal optimisation problem of farmers, necessary first-order conditions are derived and solved for analytically using the Euler equation method. The advantage of this approach is that the inter-temporal problem can be solved without making specific assumptions on the shadow price of capital as in q-theoretic models of investment (Blundell et al., 1992). The necessary first-order condition is estimated directly using the Generalised Method of Moments (GMM) estimation technique. In order to test for the presence of a binding constraint on production a GMM structural stability test is used (Hall, 1999).

The model presented in this chapter differs from previous empirical Euler equation studies (e.g. Pindyck and Rotemberg, 1983; Whited, 1998) in the way zero investments are taken into account. Previous studies consider zero investment to be optimal when the marginal benefits of investing equal the purchase price of capital. Following theoretical work by Chavas (1994), in this chapter it is assumed that investment is zero for the range in which the marginal benefits of investing are equal to or smaller than the purchase price of capital. So, an investment is made only if the marginal benefits of investing are higher than a threshold given by the purchase price of capital. From the theoretical model regimes for zero and positive investments are derived. In the empirical model only the equation for positive investment can be estimated. Assuming the model to be valid for the whole sample, but using only observations with positive investments, requires correction for selection bias in estimation.

The contributions of this chapter are twofold. First, a constraint on production is modelled explicitly into an Euler equation framework. Using structural stability tests for GMM this constraint is tested for. Second, the empirical Euler equation framework is extended to include a threshold for investment, in order to explain zero investments explicitly.

The chapter is built up as follows. In section 5.2 a short overview of Dutch manure policies in the 1980's and 1990's is given. Section 5.3 develops the theoretical framework of this chapter. In section 5.4 the empirical model, the testing procedure and other estimation issues are discussed. A description of the data is given in section 5.5. Results are presented in section 5.6 and conclusions are drawn in section 5.7.

5.2 Manure policies

Growing manure surpluses in Dutch intensive livestock production have led to increasing environmental concerns over the last two decades. In order to curb these manure surpluses the Dutch government implemented a number of environmental policies in the 1980's and 1990's. For an overview of the various elements of these agri-environmental policies see Haerkens and Walda (1994) and Heisterkamp and Bruil (1998). In this section an overview is given of those policy elements that aimed at restricting manure production[2].

[2] Other elements in the legislation are concerned with the application of manure and requirements on animal housing.

1984-1986

In 1984 the first legislation directly aiming at controlling manure production in the intensive livestock sector was introduced. The *Interimwet beperking varkens- en pluimveehouderijen* prohibited the expansion of existing farms in the south and east of the Netherlands (so-called concentration regions) by more than 10% and by more than 75% for farms in other parts of the country. Furthermore, it was not possible to establish a new farm with intensive livestock production. However, due to a large use of exceptional dispositions and a possibly weak control system this law did not achieve its objectives. In the period 1984-1987 the number of pigs increased by 28% (Algemene Rekenkamer, 1990). Therefore, the limiting effects of this law on production and investment are assumed to be minimal.

1987-1993

In 1987 phosphate based manure production rights were introduced in order to restrict the production of manure. Farms received manure production rights proportional to 125 kg phosphate per hectare (acreage based manure production rights). Moreover, each farm was allotted a reference quota of manure production rights based on the inventory of animals and standards for the manure production by animal category. By determining the area of farmland owned or long term leased, the difference between the acreage based phosphate rights and the reference quota could be calculated in order to make a distinction between manure surplus and manure deficit farms (i.e. farms with manure production larger or smaller than 125 kg phosphate per hectare). Until 1994 trade in manure production rights was prohibited. Only in very special occasions (e.g. with marriage or heritage or the transfer of a complete farm) farmers could obtain additional manure production rights. Buying additional land increased the amount of acreage based manure production rights, but this only allowed an increase in manure production for manure deficit farms. Most pig farms however, were typically manure surplus farms and therefore could not expand manure production by buying additional land. During this policy regime, expansion of pig farms in the concentration regions was brought to a standstill. Although this system appeared to be successful in stopping the growth of manure production, it is suggested that it had a negative impact on the structure of the sector. Investments, necessary for adopting innovations but also for bringing about changes in the production structure that would help solving the manure problem, seem to have been reduced or postponed in this period (Haerkens and Walda, 1994).

1994-1996

In 1994 new legislation was enacted that allowed trade of manure production rights to some extent. The amount of acreage based manure production rights could not be traded. Pig based manure production rights could be used for manure production of any type of animal but not vice versa. Furthermore, geographical restrictions on trade were set. Farmers within one of the two concentration regions could trade within their region, but could not buy manure production rights outside their region. Moreover, from the production rights transferred, 25% of them were siphoned by the government. In addition, a farmer who acquired additional manure production rights had to certify that he had either sufficient land to apply his total amount of manure or had a manure disposal contract with another farm. In the period 1994-1996, 6.4% of the total amount of tradable production rights was traded (LNV, 1996).

5.3 Theoretical framework

In this section a theoretical model of Dutch pig farmers optimising over time is developed[3]. Making assumptions on the objective of farmers and the constraints faced in optimising, necessary first-order conditions (f.o.c.'s) for optimal investment are derived. Using the so-called Euler equation approach these f.o.c.'s are combined into a necessary optimality condition holding over two subsequent time periods. Examples of the Euler equation approach can be found in e.g. Pindyck and Rotemberg (1983) and Whited (1998).

The objective of pig farmers is assumed to be the maximisation of the expected stream of future cash flows at time t:

$$PV_{ht} = E_{ht}\left[\sum_{j=0}^{\infty} r_{t+j} CF_{ht+j}\right] \tag{5.1}$$

where PV_{ht} is the expected present value for farm *h* at time *t*, E_{ht} is the expectations operator conditional on the information available to farm *h* at time *t* and r_{t+j} is the discount rate, which is defined as:

[3] The theoretical model used in this chapter is based on the model developed in Chapter four. Differences are that negative investments are not considered in the theoretical model and that one aggregate capital good consisting of buildings and machinery is modelled. Dis-aggregating capital would give too small subsamples in testing due to the large number of zero investments in the dis-aggregated subsamples.

$$r_{t+j} = \prod_{i=1}^{j} (1 + r_{t+i})^{-1} \qquad \text{and} \qquad r_t = 1$$

where r_{t+i} is the real interest rate. Equation (5.1) is maximised subject to the following constraint:

$$CF_{ht} = p_t F(X_{ht}, K_{ht}, Z_{ht}) - w_t X_{ht} - y\,(I_{ht}) - p_t^I \cdot I_{ht} \qquad (5.2)$$

Equation (5.2) defines cash flows for farm *h* in year *t* as revenues of production minus variable costs, adjustment costs and investment expenditure. Total production of pig output in year *t*, given by the production function *F(.)*, depends upon a vector of variable inputs X_{ht}, an aggregate quasi-fixed capital input K_{ht}, and a vector of fixed factors Z_{ht}. Output price is p_t and w_t denotes a vector of input prices. The adjustment cost function y is dependent on the size of gross investments in year *t*, I_{ht}. The following assumptions on the adjustment cost function are made: y is non-negative, is zero at zero investment and convex in investment. Examples of adjustment costs are learning costs, costs of restructuring the production process, administrative costs in obtaining building or environmental licenses, the value of time spent on preparing the investment, fees paid to banks in order to get a loan etc. Investment expenditure consists of the expenditure on new capital goods where p^I_t denotes the unit purchase price of capital. The capital stock is defined by

$$K_{ht} = I_{ht} + (1 - d)K_{ht-1} \qquad (5.3)$$

stating that the current capital stock consists of last year's capital stock, corrected for depreciation (*d* is the depreciation rate), plus current investment. In this study, investment is assumed to be greater than or equal to zero[4].

Manure policy aims at restricting the amount manure produced. Given the close relationship between the physical pig output and the amount of manure produced (total of manure production rights), a system of manure production rights indirectly limits physical

[4] The number of dis-investments in the dataset used is small. In total there are 13 dis-investments out of 1662 observations. An explanation for this particularly low number is that farmers who sell their buildings or equipment are likely to quit farming and therefore leave the dataset. For a more general theoretical model allowing for positive, zero and negative investment, see chapter four.

production. The effect of manure production rights on investment is therefore modelled by a potentially binding constraint on production. Production cannot exceed an upper bound $\overline{F}_{ht}$, which depends upon the quantity of manure production rights a farm has:

$$F(X_{ht}, K_{ht}, Z_{ht}) \leq \overline{F}_{ht} \tag{5.4}$$

This constraint is included in the model. Note however that in years in which manure policies were absent (1980-1983) or not assumed to be constraining production (1984-1986), the constraint is not binding and the corresponding Lagrange multiplier is automatically set to zero, removing the constraint for these years.

The problem given by the set of equations (5.1)-(5.4) can be summarised by considering it as a dynamic programming problem with corresponding Bellman equation:

$$PV_{ht}(K_{ht-1}) = \max_{x_{ht}, I_{ht}} \left\{ \begin{array}{l} p_t F(X_{ht}, I_{ht} + (1-d)K_{ht-1}, Z_{ht}) - w_t X_{ht} - y(I_{ht}) - p_t^I \cdot I_{ht} \\ + E_{ht}\left[r_{t+1} PV_{ht+1}(I_{ht} + (1-d)K_{ht-1})\right]; \\ X_{ht} > 0,\ I_{ht} \geq 0,\ F(X_{ht}, K_{ht}, Z_{ht}) \leq \overline{F}_{ht} \end{array} \right\} \tag{5.5}$$

The present value at time t depends upon the given state K_{ht-1}. In period t the control variable I_t is set to an optimal level such that in period $t+1$ the state variable is K_{ht}. In order to take the restriction on production (5.4) into account and to obtain first-order conditions the Lagrangian is written:

$$\begin{aligned} L = {} & p_t F(X_{ht}, I_{ht} + (1-d)K_{ht-1}, Z_{ht}) - w_t X_{ht} - y(I_{ht}) - p_t^I \cdot I_{ht} \\ & + E_{ht}\left[r_{t+1} PV_{ht+1}(I_{ht} + (1-d)K_{ht-1})\right] + m_{ht}\left[\overline{F}_{ht}(\cdot) - F(X_{ht}, I_{ht} + (1-d)K_{ht-1}, Z_{ht})\right] \end{aligned} \tag{5.6}$$

Note that the Lagrange multiplier m_{ht} differs by farm and over time. Differentiating with respect to X_t gives the first-order condition for variable inputs (where individual farm subscripts h are left out for convenience):

$$(p_t - m_t)\frac{\partial F_t}{\partial X_t} = w_t \tag{5.7}$$

From the Kuhn-Tucker conditions for $I_t \geq 0$ the following first-order necessary conditions for investment are derived:

$$I_t > 0 \qquad (p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_t} \right] = p_t^I + \frac{\partial y_t}{\partial I_t} \tag{5.8a}$$

$$I_t = 0 \qquad (p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_t} \right] \leq p_t^I + \frac{\partial y_t}{\partial I_t} \tag{5.8b}$$

These optimality conditions for both regimes provide a theoretical explanation for observed positive and zero investment. Equation (5.8a) states that if a farmer invests, investments are made until marginal benefits and marginal costs of investment are equated. The marginal benefits of investing consist of the marginal value product, $(p_t - m_t)\frac{\partial F_t}{\partial K_t}$, and the discounted expected dynamic shadow price of capital, $E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_t} \right]$, which reflects the change in the present value due to an increase of the capital stock. Marginal costs of investment consist of marginal adjustment costs $\partial y_t / \partial I_t$ and the purchase price of capital p^I_t. No investment is undertaken when the sum of the marginal value product and the discounted expected dynamic shadow price of capital is less than marginal costs of investment. This is given by equation (5.8b).

Differentiating either the Lagrangian in (5.6) or the Bellman equation in (5.5) with respect to state variable K_{t-1} yields:

$$\frac{\partial L}{\partial K_{t-1}} = \frac{\partial PV_t}{\partial K_{t-1}} = (1-d)\left\{ (p_t - m_t)\frac{\partial F_t}{\partial K_t} + E\left[r_{t+1} \frac{\partial PV_{t+1}}{\partial K_t} \right] \right\} = 0 \tag{5.9}$$

Using (5.8) this condition can be rewritten to:

$$I_t > 0 \qquad \frac{\partial PV_t}{\partial K_{t-1}} = (1-d)\left(\frac{\partial y_t}{\partial I_t} + p_t^I \right) \tag{5.10a}$$

$$I_t = 0 \qquad \frac{\partial PV_t}{\partial K_{t-1}} \leq (1-d)\left(\frac{\partial y_t}{\partial I_t} + p_t^I \right) \tag{5.10b}$$

Using equations (5.10) one period ahead and substituting them into equations (5.8) makes it possible to substitute out the unobservable dynamic shadow price, $\frac{\partial PV_{t+1}}{\partial K_t}$, giving the following expressions after some rewriting:

$$I_t > 0,\, I_{t+1} > 0 \qquad r_{t+1}E\left[(1-d)\left(p_{t+1}^I + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] = p_t^I + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{5.11a}$$

$$I_t = 0,\, I_{t+1} > 0 \qquad r_{t+1}E\left[(1-d)\left(p_{t+1}^I + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] \le p_t^I + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{5.11b}$$

$$I_t > 0,\, I_{t+1} = 0 \qquad r_{t+1}E\left[(1-d)\left(p_{t+1}^I + \frac{\partial y_{t+1}}{\partial I_{t+1}}\right)\right] \ge p_t^I + \frac{\partial y_t}{\partial I_t} - (p_t - m_t)\frac{\partial F_t}{\partial K_t} \tag{5.11c}$$

Note that there is one case for which no expression can be obtained, viz. $I_t = 0$, $I_{t+1} = 0$. The reason is that inequality (5.10b) one period ahead combined with inequality (5.8b), does not allow substituting out the unobservable dynamic shadow price.

These combined first order conditions have the following interpretation. The right hand side sums up the marginal costs minus the marginal benefits of investing today. The marginal costs consist of the unit purchase price of capital and the marginal adjustment cost. The marginal benefit consists of the value of marginal product in year *t*, which is not obtained if investment takes place in year *t+1*. The left-hand side represents the expected discounted sum of marginal costs of investment in period *t+1*. So, essentially these first-order conditions are a comparison of marginal investment costs over two periods. If investment takes place in both periods *t* and *t+1*, the costs in both periods should be equal, as given in equation (5.11a). The case of no investment in year *t* and positive investment in year *t+1*, case (5.11b), corresponds with higher marginal costs of investment in year *t* compared to *t+1* whereas for (5.11c) the opposite holds.

The impact of the production constraint on investment follows from the term $m_t \frac{\partial F_t}{\partial K_t}$. With the Lagrange multiplier being non-negative by definition and the marginal product of capital expected to be positive from production theory, the total term is expected to be positive. Therefore, for a given expected marginal investment cost in year *t+1* and with a binding constraint on production ($m_t>0$), the equilibrium condition holds for a smaller level of investment compared to a situation without a constraint on production. So, from this theoretical model it follows that optimal investment is reduced in the presence of a binding constraint on production.

5.4 Empirical model and estimation

Empirical analysis proceeds by estimating the first-order conditions derived from the theoretical model directly. However, since conditions (5.11b) and (5.11c) contain inequality signs and since no expression could be obtained for the case of zero investments in two subsequent years, only equation (5.11a) is estimated. As shown below, this implies a sample selection problem that has to be corrected for. Other issues that are dealt with in this section are the specification of functional forms for the production function and the adjustment cost function and the specification of the expectations formation process. Furthermore, the panel nature of the data has to be accounted for in estimation. Finally, the unobservable Lagrange multipliers m_{ht} have to be dealt with. After expounding the estimation method a testing procedure is described that allows for testing whether the constraint on production, arising from manure policies, was binding or not.

Production function

For the production function a quadratic functional form with two variable inputs (feed and other variable inputs), one aggregated quasi-fixed capital good (consisting of buildings, machinery and equipment) and three fixed factors (family labour, land and technological change) is used:

$$F(x_{ht}) = a_{0h} + \sum_{i=1}^{6} a_i x_{iht} + \tfrac{1}{2}\sum_{i=1}^{6}\sum_{j=1}^{6} a_{ij} x_{iht} x_{jht} \tag{5.12}$$

where x_{iht} denotes respectively aggregated capital (i=1), feed input (i=2), other variable input (i=3), labour (i=4), land (i=5) and technological change (i=6).

Adjustment cost function

For the adjustment cost function a flexible specification is used:

$$y\left(I_{ht}\right)=b_1 I_{ht}+\tfrac{1}{2}b_2 I_{ht}^2+\tfrac{1}{3}b_3 I_{ht}^3 \qquad (5.13)$$

Whited (1998) favoured a flexible specification over the standard quadratic adjustment cost function using a sample of U.S. manufacturing firms. He found that a quadratic specification resulted in negative adjustment cost, whereas the flexible specification restored the positive relation between investment and adjustment costs. Moreover, specification testing did not reject the flexible specification. An advantage of this flexible specification is that it allows for a variety of different adjustment cost functions (e.g. linear, quadratic, asymmetric adjustment costs). For this function to be convex in investment the second derivative with respect to investment, $y_{II}\left(I_{ht}\right)=b_2+2b_3 I_{ht}$, has to be greater than zero.

Expectations formation

Assuming rational expectations, the unobserved expected values of *t+1* variables are replaced by their realised counterparts and an expectation error e_{t+1} that captures the difference between the expected and realised values is added. Using the first order derivative of (5.12) with respect to capital and the first order derivative of (5.13) with respect to gross investment and substituting them into (5.11a), the following expression is obtained after some rewriting:

$$\begin{aligned}(1-d)\,r_{t+1}\left(b_1+b_2 I_{ht+1}+b_3 I_{ht+1}^2+p_{t+1}^I\right)-b_1-b_2 I_{ht}-b_3 I_{ht}^2-p_t^I \\ +\left(p_t-m_{ht}\right)\left(a_1+\sum_{j=1}^{6}a_{1j}x_{hj}\right)=e_{ht+1}\end{aligned} \qquad (5.14)$$

Properties of these errors are that $E\left(e_{ht+1}\right)=0$, $E\left(e_{ht+1}^2\right)=s_{ht+1}^2$ and that e_{ht+1} is uncorrelated with any time *t* information. However, although expectations on period *t+1* variables are orthogonal to the expectation errors since they are a function of period *t* variables, their realised *t+1* values are not. Therefore, OLS estimates are inconsistent and an instrumental variable estimator is necessary. In principle any period *t* variable can be used as an instrument. The Generalised Method of Moments (GMM; for an overview see Mátyás, 1999) is used to estimate (5.14) since it directly uses the above orthogonality conditions in the estimation procedure. Period *t* information is used in a vector of instruments $z_{h,t}$ and the moment condition is rewritten as $E_{ht}\left(z_{ht}\cdot e_{ht+1}\right)=0$, where e_{ht+1} is defined in (5.14).

Panel data

The panel nature of the data used allows for adding farm-specific effects to the error term. These farm-specific effects are assumed to be fixed and may reflect farm-specific differences in marginal adjustment costs or farm-specific expectation errors. To remove the fixed effects equation (5.14) is estimated in first-differences. Taking first-differences implies that the linear term of the adjustment cost function is removed. It also implies that the choice of instruments is limited. Period *t* variables are now correlated with the first-differenced expectation errors and are therefore no longer valid instruments. The moment condition now becomes $E(z_{ht-1}\Delta e_{ht+1})=0$ where Δ denotes first-differences. Valid instruments in GMM estimation with panel data consist of period *t-1* and earlier values of model variables (Arellano and Bond, 1991). The instrument set consists of two and more periods lagged values of investment, investment squared, the purchase price of capital, the output price, the price of feed, the price of other variable input and quantities of capital, family labour and land and technological change.

Sample selection bias

As shown in section two, the inter-temporal optimality conditions only yields an equality condition if investment is non-zero in both periods *t* and *t+1*. Therefore, following Alonso-Borrego (1998), estimation is conditioned on the event $D_{ht+1}=\Gamma(I_{ht+1}\cdot I_{ht}\neq 0)=1$, where $\Gamma(.)$ is the indicator function, which takes value one if the condition is true and zero otherwise. The corresponding sample selection rule is defined as:

$$\begin{aligned} D_{ht+1}&=1 \qquad if\ D^*_{ht+1}=gZ_{ht-1}+x_{ht+1}>0\\ D_{ht+1}&=0 \qquad if\ D^*_{ht+1}=gZ_{ht-1}+x_{ht+1}\leq 0 \end{aligned} \tag{5.15}$$

where D_{ht+1} is a latent variable, γ a vector of parameters and x_{ht+1} the residual of the selection equation. Under this conditioning event, the population moment condition is partitioned as:

$$\begin{aligned} E(z_{ht-1}\Delta e_{ht+1}) &= E(z_{ht-1}\Delta e_{ht+1}\mid D_{ht+1}=1)\cdot \Pr(D_{ht+1}=1)\\ &\quad + E(z_{ht-1}\Delta e_{ht+1}\mid D_{ht+1}=0)\cdot \Pr(D_{ht+1}=0)=0 \end{aligned} \tag{5.16}$$

From the partitioning it follows that the moment condition, conditional on D_{ht+1}=1 differs from the population moment condition and in general cannot expected to be zero since it only represents part of the distribution of expectation errors. Using the above partitioning of the population moment condition (5.16), the conditional moment condition is rewritten as:

$$E(z_{ht-1}\Delta e_{ht+1} \mid D_{ht+1}=1) = -E(z_{ht-1}\Delta e_{ht+1} \mid D_{ht+1}=0)\frac{\Pr(D_{ht+1}=0)}{\Pr(D_{ht+1}=1)} = \\ -z_{ht-1}E(\Delta e_{ht+1} \mid x_{ht+1} \le -gZ_{ht+1})\frac{\Pr(x_{ht+1} \le -gZ_{ht+1})}{1-\Pr(x_{ht+1} \le -gZ_{ht+1})} = -z_{ht-1}s\,\frac{f(-gZ_{ht+1})}{1-\Phi(-gZ_{ht+1})} \tag{5.17}$$

where s is the covariance between Δe_{ht+1} and x_{ht+1} (normalised by the variance of x_{ht+1}), $f(-gZ_{ht+1})$ is a normal density function and $\Phi(-gZ_{ht+1})$ is a normal distribution function. The ratio $f(-gZ_{ht+1})/(1-\Phi(-gZ_{ht+1}))$ is the Inverse Mill's ratio, which is denoted as l_{ht+1}. Correcting for sample selection bias, the following moment condition is assumed to hold:

$$E(z_{ht-1}(\Delta e_{ht+1} - s\, l_{ht+1}) \mid D_{ht+1}=1) = 0 \tag{5.18}$$

Substituting the l_{ht+1} by consistent estimates based on reduced-form probit estimates, equations (5.18) are estimated using GMM. Since it is not possible to estimate a fixed effects probit model (Maddala, 1987), the farm-specific effects cannot taken into account in calculating the Inverse Mill's ratio. Define $f_{ht}(y_h, q) = z_{ht-1}(\Delta e_{ht+1} - s\, l_{ht+1})$, where y_h is a vector of all model variables and instruments in (5.18) for farm h and q is the vector of parameters to be estimated, and define $f(y,q) = \left[\frac{1}{H}\sum_{h=1}^{H} f_{h1}(y_h, q), \ldots, \frac{1}{H}\sum_{h=1}^{H} f_{hT-1}(y_h, q)\right]$, then $\hat{q}_{GMM}$ is the estimator that minimises the objective function:

$$Q(q) = f(y,q)' V^{-1} f(y,q) \tag{5.19}$$

where V^{-1} is a weighting matrix. The GMM estimator is particularly apt for equations like (5.18). It can handle non-linear equations and allows for heteroskedastic errors. Furthermore, distributional assumptions on the data (e.g. normality) are not necessary (Ogaki, 1999).

Testing procedure

In the equation to be estimated the unobserved Lagrange multipliers $m_{h,t}$, corresponding to the constraint on production, are present. An approach that is often applied in the literature on borrowing constraints (see e.g. Whited, 1992; Hubbard and Kashyap, 1992) is to assume that the unobservable Lagrange multipliers are a linear function of some observable variables and to substitute this function into the Euler equation. If borrowing constraints are present then the parameters of the substituted function should be significant and a reduction in the value of the GMM objective function should be observed. However, instead of this (arbitrary) substitution of the unobservable Lagrange multipliers by related variables, in this chapter the presence of binding constraints on production in the Euler investment equation is directly tested for. The testing procedure is based on structural stability tests for GMM developed by Hall and Sen (1999).

In order to explain the testing procedure, equation (5.14) is rewritten so that the product of the Lagrange multiplier with the marginal product of capital is on the right-hand side:

$$\begin{aligned}(1-d)r_{t+1}\left(b_2 I_{ht+1} + b_3 I_{ht+1}^2 + p_{t+1}^I\right) - b_2 I_{ht} - b_3 I_{ht}^2 - p_t^I + p_t\left(a_1 + \sum_{j=1}^{6} a_{1j} x_{hj}\right) = \\ e_{ht+1} + m_{ht}\left(a_1 + \sum_{j=1}^{6} a_{1j} x_{hj}\right)\end{aligned} \qquad (5.20)$$

Since interest is in the potential constraining effects of the system of manure production rights introduced in 1987, the constraint on production is assumed to be present from 1987 on. In the years before 1987, the Lagrange multiplier is assumed to be zero. In that case, estimation is straightforward using the left-hand side in estimation. If from 1987 on the constraint is not binding for farms, estimation does not differ from the period before 1987 since the left-hand side of (5.20) again defines the expectation error in the moment condition. However, if the constraint is binding for farms over a number of years, the left-hand side of (5.20), which determines e_{ht+1} in the unconstrained case, cannot be expected to be zero anymore, due to the presence of the positive Lagrange multiplier. Therefore, a natural way of testing for the presence of a production constraint is to test whether or not the moment conditions, based on the left-hand side of (5.20), hold before and after 1987. This is similar to testing whether the overidentifying restrictions hold before and after 1987 because if the production constraint is present and binding after 1987, a model that does not take this constraint into account is misspecified[5]. So, the null hypothesis states that the overidentifying restrictions hold both before and after the structural breakpoint 1987[6], which is similar to the hypothesis that the constraint on production was not binding. The alternative is that the overidentifying restrictions do not hold in the period after 1987, which may have been caused by the binding constraint on production. The test statistic is defined as $J = J1 + J2$ where $J1$ and $J2$ are the *J*-test statistics from the overidentifying restrictions test for respectively the period before and after 1987. Under the null hypothesis that the overidentifying restrictions hold in both periods the test statistic follows a c^2 distribution with degrees of freedom equal to twice the number of overidentifying restrictions (Hall and Sen, 1999).

5.5 Data

Data on specialised pig farms covering the period 1980-1996 are obtained from a stratified sample of Dutch farms keeping accounts on behalf of the Dutch Agricultural Economics Research Institute (LEI) farm accounting system. Farms were selected if the share of pig output in total output exceeds 80%. The farms remain in the panel for about five to seven years, so the panel is unbalanced.

An implicit value for capital is obtained by dividing the sum of capital invested in buildings, machinery and equipment by a Tornquist price index. Capital investment is defined as the sum of investments and dis-investments. In estimation the discount factor and the depreciation rate are considered constant. The discount factor used is based on the average real interest rate over the estimation period and equals 0.95. The depreciation rate for capital is assumed to be 5%[7]. The first-order derivative of the production function with respect to capital contains two variable inputs, pig feed and other variable inputs (e.g. veterinary costs, heating, electricity, hired labour and various other costs) and capital, family labour, land and technological change. The output price is a Tornquist price index calculated with prices obtained from LEI/Statistics Netherlands (several years). The implicit quantity of capital is

[5] For a discussion on identifying and overidentifying restrictions see Hall (1999).
[6] Hall and Sen (1999) provide a rigorous technical discussion on structural break tests in GMM estimation. By decomposing the population moment restrictions into identifying and overidentifying restrictions, they derive a test for parameter stability and a test for model misspecification due to a structural breakpoint.
[7] In chapter four, a depreciation of 4% is used for buildings and a rate of 10% for machinery and equipment. Taking into account that buildings have a high share in aggregated capital (about 85%), a depreciation rate of 5% is the average.

measured at constant 1980 prices, total farm family labour is measured in hours and land is measured in hectares.

Taking first differences and using twice-lagged values of endogenous variables implies that only farms with three or more observations can be used in estimation and that data for 1980 and 1981 can only be used as instruments. Removing farms with one or two observations and 13 observations with negative investments results in a data set with 882 observations on 281 farms. Basic statistics of the data are given in table IV.1 in appendix IV.

Table 5.1 gives averages for investment for the three periods of interest in this study: the period before the introduction of the manure production rights (1980-1986), the period in which these non-tradable rights were introduced (1987-1993) and the period in which these rights were made tradable to some extent (1994-1996). Looking at sample averages for investment as given in table 5.1 suggests that the system of manure production rights may have reduced investments.

Table 5.1 Sample averages for investment and investment/capital ratio (standard deviations in parentheses)

Period	Sample average I_t	Sample average I_t/K_t	N
1980-1986	0.496 (0.991)	0.099 (0.194)	225
1987-1993	0.474 (1.100)	0.078 (0.143)	445
1994-1996	0.621 (1.183)	0.094 (0.190)	212
Total	0.515 (1.095)	0.088 (0.169)	882

As shown in the first column of table 5.1, average investment does not differ much for the first two periods but it is considerably higher in the period 1994-1996. However, looking at investment only does not take the ongoing increase in scale of farms into account. Therefore in the second column the investment/capital ratio is given. This ratio suggests that investment was considerably lower in the period 1987-1993 than in the other two periods. The higher investment/capital ratio in the period 1994-1996 suggests that the limited tradability of the manure production rights in this period raised investments again. Although the observed pattern of average investment is what would be expected, this does not necessarily imply that the observed pattern is due to restrictions imposed by manure policy. Other variables could be the real underlying cause (e.g. low output prices). The model developed in the previous two sections takes into account the various variables that have an impact on investment and can therefore provide a better answer to the question whether manure policy has restricted investment than looking at the averages in table 5.1.

5.6 Results

In this section estimation results and the results of the testing procedure for production constraints are discussed. First, reduced form probit estimates are given that are used to obtain the Inverse Mill's ratio for sample selection bias correction. Second, the parameter estimates for the Euler equation are presented and discussed. Next, the results of the testing procedure for a constraint on production for the period 1987-1996 are given. Finally, it is investigated whether financial variables had an impact on investment.

Sample selection bias

In order to control for sample selection bias, arising from using only observations with positive investment in the estimation of the inter-temporal optimality condition (5.14), first a probit reduced form is estimated for the event $D_{h,t+1}=1$. In order to have the Inverse Mill's ratio uncorrelated with the prediction error, two-, three- and four-period lagged variables are used in this reduced probit estimation. The estimation results are given in table IV.2 in appendix IV.

Significant variables in explaining capital investment in two consecutive periods are the two and three period lagged values of investment, the amount of labour and land two periods lagged and the output price three periods lagged. The positive impact of lagged investments implies that the more a farm invested in the past, the higher the probability of investing in two consecutive periods in the future. The positive impact of land and labour suggests that farms with larger quantities of these factors also invest more often in capital. Although the probit model gives a correct prediction for 658 of the total 882 (75%) zero and positive observations in the total sample, the McFadden's R^2 of 0.12 indicates that the model variables have little explanatory power.

Euler equation parameter estimates

Using these parameter estimates, the Inverse Mill's ratio is calculated for observations with positive investment in two consecutive periods and is included in the Euler equation as additional regressor. Parameter estimates for the Euler equation over the whole period 1982-1996 are given in the first column of table 5.2.

Table 5.2 Parameter estimates for the Euler equation (standard errors in parentheses)

	1982-1996	1982-1986	1987-1996	1987-1993	1994-1996
α_1	-0.136 (0.092)	0.214 (0.052)*	-0.042 (0.078)	-0.179 (0.030)*	0.045 (0.016)*
α_{11}	0.006 (0.005)	0.013 (0.005)*	0.001 (0.003)	0.020 (0.005)*	$1.9*10^{-4}$ (0.001)
α_{12}	0.047 (0.017)*	-0.039 (0.011)*	0.030 (0.010)*	-0.010 (0.005)*	0.003 (0.001)*
α_{13}	-0.056 (0.029)*	-0.019 (0.029)	-0.032 (0.019)	0.006 (0.014)	-0.001 (0.002)
α_{14}	0.023 (0.017)	-0.013 (0.009)	0.017 (0.014)	-0.016 (0.006)*	0.001 (0.002)
α_{15}	0.002 (0.004)	-0.006 (0.004)	0.001 (0.002)	-0.003 (0.001)*	$2.0*10^{-4}$ ($1.9*10^{-4}$)
α_{16}	-0.010 (0.005)*	0.030 (0.004)*	-0.012 (0.005)*	0.019 (0.002)*	-0.005 (0.001)*
β_2	-0.025 (0.008)*	-0.006 (0.005)	-0.001 (0.008)	-0.028 (0.006)*	0.007 (0.001)*
β_3	0.001 (0.001)	0.001 (0.001)	$2.0*10^{-4}$ (0.001)	0.002 (0.001)	$4.7*10^{-4}$ ($9.5*10^{-5}$)*
σ	-0.022 (0.010)*	0.101 (0.011)*	-0.033 (0.010)*	0.043 (0.007)*	-0.017 (0.002)*
J-statistic (d.f.)	22.07 (20)	31.78 (20)	41.86 (20)	58.37 (20)	36.73 (20)
N	650	165	485	333	152

* Significant at the 5% level

For the total sample period 5 of the 11 parameters are significant at the 5% level. The parameters from the marginal product of capital (a_{ij}'s) have the following interpretation. The value marginal product of capital is increasing in the stock of capital (parameter not significantly different from zero at 5% level), feed input (significant), labour and land (both not significant). It is decreasing in output price (not significant), other variable inputs (significant) and technological change (significant). From equation (5.14) it follows that a high marginal product of capital has a positive effect on investment in period *t*. So, large quantities of capital, feed, labour and land have a positive effect on investment in period *t*, whereas the output price, other variable inputs and technological change have a negative effect on investment. Although they are not significant at the 5% level, especially the signs of the stock of capital and the output price are opposite to their expected signs. Using the parameters a_{ij} it can also be checked whether the production function is increasing in capital for all observations. It appears that for only 50% of the observations this theoretical requirement holds. The parameter estimates for the adjustment cost function are not in accordance with standard adjustment cost theory. The negative parameter for the quadratic term (significant at the 5% level) suggests that marginal adjustment costs are decreasing over a large range. Due to the positive cubic term (not significant) marginal adjustment costs will eventually rise again. Whether adjustment costs are positive over the whole range depends upon the linear adjustment cost term. However, this was removed by first-differencing and it is not possible to calculate this parameter *ex post* since it cannot be separated from the average of the farm-specific effect. The implication of the non-linear adjustment cost terms is that for a large range of investments it is optimal to invest more than the observed quantity, since marginal adjustment costs are decreasing in this range. That farmers do not invest more may be due to restrictions (e.g. credit restrictions or restrictions imposed by the (local) government) preventing them from investing optimal quantities. The parameter of the Inverse Mill's ratio is significant at the 5% level, indicating that using only positive observations without correction using an Inverse Mill's Ratio, yields biased estimates due to sample selection.

The impact of manure production rights

The *J*-statistic, which is the test statistic for testing whether the overidentifying restrictions hold, has a value of 22.07, which is smaller than the critical $c^{2}_{20;0.95}$ level of 31.41. This indicates that the model is not misspecified for the whole period. It suggests that for the whole sample period, a model without a binding constraint on production could be used to explain investment behaviour. However, since the constraint was already absent for a number of years and since it may not have been binding throughout the whole period 1987-1996, it is worthwhile to look at the model estimates for the subsamples 1982-1986 and 1987-1996 and test for a structural break in 1987.

Next, the sample is split over the periods 1982-1986 and 1987-1996 in order to test for a structural break at 1987 and to test whether the model is rejected for the period 1987-1996. The model is re-estimated for both periods and the parameter estimates for the respective periods are given in column two and three of table 5.2. For the period 1987-1996, the parameter estimates do not differ much with respect to size, sign and significance from those for the total sample period, so that interpretation of the parameters is the same. The *J*-statistic of 41.86 however indicates misspecification of the model in this case. The estimates for the period 1982-1986 are somewhat different however. The value marginal product of capital is now increasing in output price, the stock of capital and technological change with all three parameters significantly different from zero. High output prices, a large stock of capital and a high state of technology have positive effects on investment in period *t*. Feed input (significant), other variable input, labour and land (all three not significant) have a negative effect on period *t* investment, through the value marginal product of capital. Using parameters and data for this period shows that production is now increasing in capital for all observations.

The positive and significant parameter a_{11} indicates that there are increasing marginal returns of capital in production. Parameter estimates for the adjustment cost function are again negative for the quadratic term and positive for the cubic term, both not significant at the 5% level, however. The *J*-statistic of 31.78 indicates that the model is only just rejected at the 5% level of significance (critical value is 31.41).

In order to test for a structural break between the periods 1982-1986 and 1987-1996 the test statistic is calculated by adding up the two values of the *J*-test statistics of both subsample estimations, yielding a structural break test statistic of 73.64, which is larger than the critical level of $c^2_{40;0.95}$ = 55.76. Therefore, the null hypothesis that the overidentifying restrictions hold before and after the breakpoint, i.e. the model is correctly specified before and after 1987, is firmly rejected. In other words, the hypothesis that manure productions rights did not have a constraining effect on production, affecting investment decisions of farmers, is rejected. The individual overidentifying restrictions tests suggest that before 1987 the model is correctly specified and that after 1987 the model is misspecified.

It is interesting to test whether the change in the system of manure production rights from non-tradable to tradable manure production rights relaxed the constraint on production. If this is true, the model would be rejected for the period 1987-1993 and not rejected for 1994-1996. Therefore the model is also estimated using these subsamples. The results are given in the fourth and fifth column of table 5.2. For the period 1987-1993 the model is firmly rejected with a *J*-statistic of 58.37. For the period 1994-1996, the *J*-statistic yields the considerably lower value of 36.72, which still indicates rejection of the model at the 5% level of significance. The structural break test statistic has a value of 95.10, indicating that the overidentifying restrictions do not hold both before and after 1994. The lower *J*-test statistic for the period 1994-1996 however suggests that the production constraint may have become less binding in the latter period due to tradability of the manure production rights.

Borrowing constraints

The results provide evidence for the presence of binding constraints on production arising from the manure policies implemented in 1987 and a relaxation of this constraint in 1994. However, it could well be that the structural break found in 1987 has other causes. In the literature, rejection of the overidentifying restrictions has often been attributed to the presence of borrowing constraints that are not taken into account in this model (Whited, 1992; Hubbard and Kashyap, 1992). It might well be that rejection of the model for the period 1987-1996 is due to the presence of borrowing constraints that were absent in the period 1982-1986. The financial position of farms may have worsened so that it was harder to obtain loans or banks may have become more risk averse in supplying funds due to rising uncertainty about the viability of the pig sector.

Extending the model by explicitly including borrowing constraints gives the same problem as the presence of production constraints. If the borrowing constraint is binding, another unobservable Lagrange multiplier is introduced in the model. A more simple procedure is to split the 1987-1996 sample into a set of farms which is expected to be financially constrained, and a set with farms that are not. Therefore, a debt-asset ratio is calculated for each farm and farms with a debt-asset ratio higher than 70% are separated from the sample. A debt-asset ratio of 70% and higher is usually seen as critical in obtaining loans (Mulder, 1994: 115). Debts are defined as the sum of long-term loans and short-term debts and the asset value is the total balance value of assets. This yields a dataset containing 396 observations on 149 farms with a debt-asset ratio lower than 70%, which are considered not to be financially constrained. Only 33 farms (78 observations) had a higher debt-ratio and 8 out of 190 farms present in this period had no observations on debts and loans. The dataset with farms that are expected not to be financially constrained was used to estimate the model for the period 1987-1996. If borrowing constraints were the real underlying cause of the rejection of the model in this period, then the model should not be rejected using this sample. However, the *J*-test statistic for this estimation has a value 35.00, which still leads us to reject the model for this period. So, this indicates that borrowing constraints are not the underlying cause for model rejection in the period 1987-1996.

5.7 Conclusions and discussion

The objective of this chapter is to assess whether manure production rights had a significant constraining effect on capital investment in the Dutch pig sector over the period 1987-1996. In order to answer this question an inter-temporal model of investment is developed, which is augmented by a (potentially binding) constraint on production arising from the introduction of manure production rights. The model developed in this chapter provides an explanation for the occurrence of zero investments by assuming that investment is zero for the range in which the marginal benefits of investing are equal to or smaller than the purchase price of capital leading to regimes for zero and positive investments.

In the theoretical model it is shown that a constraint on production implies a reduction in investment. Furthermore, the empirical model shows that testing for the presence of these constraints is straightforward using a GMM structural break test. If a binding constraint on production was present in the period 1987-1996, then the unrestricted model is misspecified, since the constraint is not taken into account. Direct modelling of the restricted model with a binding constraint on production is not possible due to the unobservable Lagrange multiplier.

Although the model is not rejected for the whole sample period, its estimates are not satisfactory. Parameter estimates for both the production function and the adjustment cost function are not in accordance with theory. Estimates using the pre-manure production rights period (1982-1986) sample however, are in line with theory, whereas the estimates for the manure production rights period (1987-1996) are comparable to those for the whole sample.

Using a GMM test for a known breakpoint provides evidence for the presence of a structural break in 1987, supporting the hypothesis that manure policy has reduced investments and therefore affected the long-run development of the Dutch pig sector. Estimating the model for the periods 1987-1993 and 1994-1996 and applying this test for the year 1994, in which manure production rights became tradable, shows that the constraint on production became less binding due to the tradability of manure production rights.

Although the presence of a structural break in 1987 was demonstrated, this does not automatically mean that this was caused by a binding constraint on production arising from manure policy. There can be other sources for model rejection in the manure policy period such as borrowing constraints or other aspects of the investment process that are not taken into account in the model. Therefore, one should be careful with using the results. However, using a subsample of farms that are not expected to be financially constrained still leads us to reject the model for the period 1987-1996, which confirms the conclusion that manure production rights affected investment processes negatively through its effects on production.

CHAPTER 6

CONCLUSIONS AND DISCUSSION

6.1 Introduction

This final chapter summarises the main conclusions of the previous four chapters and gives implications for the Dutch pig sector in section 6.2. Two central issues of this thesis, viz. long-run theories of factor adjustment and dealing with heterogeneity using panel data techniques, are discussed in section 6.3. Finally, section 6.4 provides some directions for future research.

6.2 Summary of main conclusions

In chapter one, four objectives are defined that are worked out in the chapters 2-5. In this section the main conclusions are summarised and implications for the Dutch pig sector are given. In the individual chapters the conclusions are discussed more in depth.

In chapter two the main conclusion is that the farm-specific effects in a system of output supply and input demand equations for Dutch pig breeding farms are correlated with buildings and machinery and installations. Since Dutch pig breeding farmers differ mainly in technical skills and skills in organising the production process, together denoted by an aggregate management variable, it can be concluded that differences in management are related to different quantities of these capital goods. Results indicate that pig farms with good management have more buildings and machinery than pig farms with poor management. Although the correlation between management and the quantity of capital does not imply a direct causal relationship, it can be inferred that either good management is a determinant in capital investment or that a large capital base enables a pig farmer to improve upon its management skills.

In chapter three a short-run model is developed in which the quantity of available quasi-fixed factors cannot be changed, but where the utilisation of available quasi-fixed factors can be below full utilisation. The model is applied to the 1998 Dutch pig sector restructuring law. Farmers were forced to reduce their production, leading to under-utilisation of available pig places. Theoretically and empirically it is shown that under-utilisation leads to lower shadow prices of production rights for breeding pigs. With tradable quotas this implies that pig breeding farmers are less willing to buy additional pig production rights. If quotas are not tradable this result is important for the government who buys out individual pig farmers. Compensation for bought out production rights could be lower taking under-utilisation into account.

Where chapter three considers the utilisation of available quasi-fixed factors in the short-run, chapter four explicitly looks at adjustment of quantities of buildings and machinery. A generalised investment model for Dutch pig farmers, integrating fixed asset theory and adjustment cost theory in one coherent framework, is specified and estimated for buildings and machinery. The main conclusion is that adjustment costs are important determinants in investment for buildings but not for machinery. This implies that when farmers adjust the stock of machinery, this adjustment is instantaneous. Furthermore, it was hypothesised that farmers have different thresholds for investment, represented by a farm-specific linear term in the adjustment cost function. Testing indicates that joint farm-specific parameters, which include farm-specific thresholds for investment and farm-specific effects, are present in the optimality conditions for investment. However, farm-specific thresholds cannot be calculated since they cannot be separated from other elements in the joint farm-specific parameters.

In chapter five the impact of manure production rights on capital investment is tested for. Manure production rights were introduced in 1987. In the theoretical model it is shown that a constraint on production implies a reduction in investment. The research question is whether such a constraining effect was present or not. A testing procedure, based on a GMM structural break test, is developed and implemented. The results provide evidence for a negative impact of manure production rights on investment after 1987. Lower investments in the period after 1987 may have weakened the future viability of the pig sector.

6.3 Discussion

In this section two central issues of this thesis are discussed. The first is the theory of long-run factor adjustment, which is an important issue in chapters four and five. The second issue is dealing with heterogeneity using panel data techniques.

Long-run theories of factor adjustment

The generalised investment model presented in chapters four and five combines fixed asset theory and adjustment cost theory in one dynamic model. Fixed asset theory provides a theoretical motivation for observed zero investments, whereas adjustment cost theory motivates spreading of investments over time.

The empirical evidence for both theories in this thesis is mixed. In chapter four, the generalised model with a flexible adjustment cost function was rejected for machinery but not for buildings. Parameter estimates also indicated convex adjustment costs for buildings. This indicates that sluggish adjustment over time occurs for buildings but not for machinery. Taken into account that machinery is easier to add or replace than buildings, this is a plausible finding. In chapter five there was only evidence for sluggish adjustment due to convex adjustment cost for the subsample 1994-1996. Both the quadratic and cubic adjustment cost term were positive, indicating convex adjustment costs. For the total sample and other subsamples, quadratic and cubic terms were either not significant or negative, conflicting with standard adjustment cost theory. So, from chapter four there is support for adjustment cost theory in the case of buildings but not for machinery, whereas in chapter five, using aggregate capital, only for one subsample the adjustment cost parameters correspond to sluggish adjustment. Given the findings in chapter four, the results in chapter five may be due to capital aggregation.

In chapters four and five asset fixity was modelled using farm-specific linear adjustment cost terms. However, in the presence of farm-specific effects in the optimality conditions for investment, these farm-specific linear adjustment cost parameters cannot be separated from other elements in the farm-specific effects, e.g. management or farm-specific prediction errors. If farm-specific effects are not present, a linear adjustment cost parameter that is equal for all farms can be estimated. In chapter four, testing indicated presence of joint farm-specific parameters in the model. These joint farm-specific parameters include farm-specific thresholds for investment, but they cannot be obtained. Summarising, the empirical evidence for asset fixity due to adjustment costs is limited. Inclusion of selling prices may improve the empirical underpinning of fixed asset theory and provide a better explanation for zero investments. Moreover, alternative explanations for zero investments may also help explain the observed number of zero investments. For example, recent theoretical work stresses the importance of uncertainty in explaining investment (Dixit and Pindyck, 1994). Extending the modelling framework with uncertainty is discussed in section 6.4.

Heterogeneity and panel data techniques

In this thesis unobserved characteristics of individual farms are taken into account in the models used. The panel structure of the data allows for this refinement in modelling and panel data estimation techniques are available to account for these farm-specific effects. Inclusion of farm-specific effects enriches the empirical model structure, since it accounts for differences among farms. However, the interpretation of these farm-specific effects is not always clear. In a production or profit function model for pig farmers one can reasonably assume that the major factor that is missing and in which farms differ is the unobserved management variable. However, in chapters four and five it is not possible to give a clear-cut interpretation of these farm-specific effects.

Another problem is that only joint statistical significance of the farm-specific effects can be tested, leaving questions about significance for individual farmers. Moreover, since panel data techniques account for farm-specific effects by taking first-differences or deviations from the means, these effects can only be calculated *ex post* and no theoretical restrictions can be imposed upon them *ex ante*. In other words, it is known how to deal with farm-specific effects in empirical models, but interpretation is more problematic.

6.4 Future research

Based on the results and conclusions obtained in this thesis, a number of suggestions for future research can be made. The results of this thesis depend upon the assumptions made in the individual chapters. A first line of research could focus on using alternative or additional assumptions in modelling capital adjustment. For example, in chapters four and five rational expectations were assumed. The motivation for this assumption is given in chapter four. However, it could well be that farmers' expectations are better described by alternative expectation formation processes. Therefore, validity of the rational expectations hypothesis should be tested (e.g. Thijssen, 1996) and the implications of other assumptions on expectation formation for investment behaviour should be worked out. Another example is the assumed objective of farmers. Based on neo-classical production theory it is assumed throughout this thesis that farmers optimise an objective function (short-run profits or the expected stream of future cash flows) subject to a set of constraints. From this optimisation problem optimal conditions are derived and used in estimation. However, it could be that farmers have additional objectives that have an impact on investment decisions. Additional objectives could be continuation of the farm business or maximisation of technical results (for an overview see Gasson et al., 1987). Using a multiple objective framework it is interesting to investigate what the impact of such alternative objectives on investment decisions would be. Additional explanations for investment could be added to the generalised investment model developed in this thesis. For example the impact of income taxes on investment decisions could be taken into account. Elhorst (1993) found that financial variables and personal characteristics correlate with investment of Dutch dairy farmers. It should be noted however that a number of these variables are also represented by the farm-specific effects used in the models of chapter four and five.

Another line of research focuses on improvements in estimation of the generalised investment model developed in chapter four. For this model that combines fixed asset theory and adjustment cost theory optimal conditions are derived and estimated. However, two problems were encountered in estimation. The first is that optimal conditions for zero investment can be derived but cannot be used in estimation since they involve inequality conditions. This has two implications. The first is that datasets with a large number of zero investments lead to inefficient estimates, since the large number of zero observations is not fully used in estimation. A second implication is that a system of investment equations for a number of quasi-fixed factors cannot be estimated. Since the number of zero observations usually differs for different quasi-fixed factors, the number of observations that can be used in estimation differs for each quasi-fixed factor. Note that this problem is also present in the papers by Chang and Stefanou (1988) and Oude Lansink and Stefanou (1997). The second problem is that the farm-specific linear adjustment cost parameters could not be obtained since they cannot be separated from the farm-specific effects. This not only makes it impossible to obtain the adjustment cost functions for individual farms, but it also implies that the model cannot be used for simulations.

An estimation method that can deal with these problem is maximum entropy econometrics (Golan et al., 1997; Mittelhammer et al., 2000). This estimation approach can include both equality and inequality conditions in estimation and it allows for estimation of the optimality conditions for individual farms with only a small number of observations. In estimation farm-specific linear adjustment cost terms can be separated from the farm-specific effects. An additional advantage is that theoretical model properties are straightforward to include in estimation.

A third promising area of research, which also focuses on estimation of the model developed in chapter four, combines dynamic programming techniques with advanced estimation methods. In chapters four and five necessary first order-conditions for an optimum were derived and estimated using GMM. An alternative approach is to solve the dynamic programming problem numerically. Different numerical procedures and estimation strategies have been proposed. For an overview of this approach see Rust (1996). Applications of this approach are found in Winter (1998) and Pietola and Oude Lansink (2001). A potential advantage of this approach is its wider applicability. Investment problems, but also switching problems (e.g. to another production technique) can be incorporated in this framework.

Finally, the effects of uncertainty on investment could be modelled. In chapters four and five it is assumed that farmers maximise the expected stream of future cash-flows. For the optimality conditions derived, it is assumed that expectations are formed rationally and the expected values of future variables are replaced by their realised value and an expectation error is added. In this respect uncertainty about future values of variables has no effect on investment decisions. However, uncertainty may also have a direct influence upon farmers' decisions. When there is uncertainty about future prices or policies and farmers can postpone investments, they have an option to invest. They can wait for more information in order to avoid future losses. According to Dixit and Pindyck (1994), this option to invest should be taken into account in investment decisions. However, statistical evidence for this theory has been limited thus far (Dixit and Pindyck, 1994:423). Most empirical studies based on this option theory of investment obtain investment thresholds using simulation techniques and a given price variability (e.g. Price and Wetzstein, 1998). Therefore, it would be interesting to investigate whether the effect of uncertainty can be incorporated in the investment model developed in chapter four. Since the necessary optimality condition provides a comparison of marginal costs of adjustment in periods t and $t+1$, it seems straightforward to include the option value in this comparison. However, the theoretical properties and empirical implementation of such a model have to be worked out.

REFERENCES

Abel, A.B. (1983). Optimal Investment under Uncertainty. *American Economic Review* 73: 228-233.

Abel, A.B. and Eberly, J.C. (1994). A Unified Model of Investment Under Uncertainty. *American Economic Review* 84: 1369-1384.

Algemene Rekenkamer (1990). Decemberverslag vergaderjaar 1990-1991, 21955, no. 1-2, Den Haag.

Alonso-Borrego, C. (1998). Demand for labour inputs and adjustment costs: evidence from Spanish manufacturing firms. *Labour Economics* 5: 475-497.

Alston, J.M. (1981). A Note on the Effects of Non-Transferable Quotas on Supply Functions. *Review of Marketing and Agricultural Economics* 49: 189-197.

Amemiya, T. and MaCurdy, T.E. (1986). Instrumental-Variable Estimation of an Error-Components Model. *Econometrica* 54: 869-880.

Arellano, M. and Bond, S. (1991). Some test of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277-279.

Babcock, B.A. and Foster, W.E. (1992). Economic Rents Under Supply Controls with Marketable Quota. *American Journal of Agricultural Economics* 74: 630-637.

Baltagi, B.H. (1995). *Econometric Analysis of Panel Data*. Chichester: John Wiley & Sons.

Baltagi, B.H. and Khanti-Akom, S. (1990). On Efficient Estimation with Panel Data: An empirical comparison of instrumental variables estimators. *Journal of Applied Econometrics* 5: 401-406.

Beattie, B.R. and Taylor, C.R. (1985). *The Economics of Production*. New York: John Wiley and Sons.

Berndt, E.R. and Morrison, C.J. (1981). Capacity Utilization Measures: Underlying Economic Theory and an Alternative Approach. *American Economic Review* 71: 48-52.

Blundell, R., Bond, S. and Meghir, C. (1993). Econometric Models of Company Investment. In: Mátyás, L. and Sevestre, P. (eds.). *The econometrics of panel data: Handbook of theory and applications*. Advanced Studies in Theoretical and Applied Econometrics, vol. 28. Norwell, Mass. and Dordrecht: Kluwer Academic.

Boots, M., Oude Lansink, A., Peerlings, J. (1997). Efficiency loss due to distortions in Dutch milk quota trade. *European Review of Agricultural Economics* 24: 31-46.

Breusch, T.S., Mizon, G.E. and Schmidt, P. (1989). Efficient Estimation Using Panel Data. *Econometrica* 57: 695-700.

Carpentier, A. and Weaver, R.D. (1997). Damage Control Productivity: Why Econometrics Matters. *American Journal of Agricultural Economics* 79: 47-61.

Chang, C.C. and Stefanou, S.E. (1988). Specification and Estimation of Asymmetric Adjustment Rates for Quasi-Fixed Factors of Production. *Journal of Economic Dynamics and Control* 12: 145-151.

Chavas, J.P. (1994). Production and Investment Decisions Under Sunk Cost and Temporal Uncertainty. *American Journal of Agricultural Economics* 76: 114-127.

Chirinko, R.S. (1993). Business Fixed Investment Spending: Modeling Strategies, Empirical Results, and Policy Implications. *Journal of Economic Literature* 31: 1875-1911.

Cochrane, W.W. (1955). Conceptualizing the Supply Relation in Agriculture. *Journal of Farm Economics* 37: 1161-1176.

Cornwell, C. and Rupert, P. (1988). Efficient Estimation with Panel Data: An empirical comparison of instrumental variables estimators. *Journal of Applied Econometrics* 3: 149-155.

Cox, T.L. and Wohlgenant, M.K. (1986). Prices and quality effects in cross-sectional demand analysis. *American Journal of Agricultural Economics* 68: 908-919.

Davidson, R. and Harris, R. (1981). Non-Convexities in Continuous-Time Investment Theory. *Review of Economic Studies* 48: 235-253.

Diewert, W.E. and Wales, T.J. (1987). Flexible functional forms and global curvature conditions. *Econometrica* 55: 43-68.

Dixit, A.K. and Pindyck, R.S. (1994). *Investment under Uncertainty*. Princeton: Princeton University Press.

Edwards, C. (1959). Asset Fixity and the Farm Organization. *Journal of Farm Economics* 37: 747-759.

Elhorst, J.P. (1993). The estimation of investment equations at the farm level. *European Review of Agricultural Economics* 20: 167-182.

Frouws, J. (1994). *Mest en Macht. Een politiek-sociologische studie naar belangen-behartiging en beleidsvorming inzake de mestproblematiek in Nederland vanaf 1970.* PhD-thesis. Wageningen: Wageningen Agricultural University.

Fulginiti, L. and Perrin, R. (1993). The Theory and Measurement of Producer Response under Quotas. *Review of Economics and Statistics* 75: 97-106.

Gardner, R. (1998). Unobservable individual effects in unbalanced panel data. *Economics Letters* 58: 39-42.

Gasson, R., Crow, G., Errington, A., Hutson, J., Marsden, T. and Winter, D.W. (1988). The farm as a family business: a review. *Journal of Agricultural Economics* 39: 1-42.

Golan, A., Judge, G. and Miller, D. (1996). *Maximum entropy econometrics: robust estimation with limited data*. Chichester: John Wiley & Sons.

Greene, W.H. (1997). *Econometric Analysis*. London: Prentice-Hall International.

Guyomard, H., Delache, X., Irz, X. and Mahe, L.P. (1996). A Microeconometric Analysis of Milk Quota Transfer: Application to French Producers. *Journal of Agricultural Economics* 47: 206-223.

Haerkens, H.M.J. and Walda, H.C.A. (1994). De Wet verplaatsing mestproduktie. *Agrarisch Recht* 54: 1-20.

Hall, A.R. (1999). Hypothesis Testing in Models Estimated by GMM. In Mátyás, L. (ed.), *Generalized Method of Moments Estimation*. Cambridge: Cambridge University Press, 96-127.

Hall, A.R. and Sen, A. (1999). Structural Stability Testing in Models Estimated by Generalized Method of Moments. *Journal of Business and Economic Statistics* 17: 335-348.

Hallam, D. and Machado, F. (1996). Efficiency Analysis with Panel Data: A Study of Portuguese Dairy Farms. *European Review of Agricultural Economics* 23: 79-93

Hamermesh, D.S. and Pfann, G.A. (1996). Adjustment Costs in Factor Demand. *Journal of Economic Literature* 34: 1264-1292.

Hausman, J.A. (1978). Specification Tests in Econometrics. *Econometrica* 46: 1251-1271.

Hausman, J.A., Taylor, W.E. (1981). Panel Data and Unobservable Individual Effects. *Econometrica* 49: 1377-1398.

Heisterkamp, A.H.T. and Bruil, D.W. (1998). *Tekstuitgave Pachtwet/Wetgeving landelijk gebied 98/99*. Deventer: Kluwer.

Holtz-Eakin, D. (1988). Testing for individual effects in autoregressive models. *Journal of Econometrics* 39: 297-307.

Howard, W.H. and Shumway, C.R. (1988). Dynamic Adjustment in the U.S. Dairy Industry. *American Journal of Agricultural Economics* 70: 837-847.

Hsu, S.H. and Chang, C.C. (1990). An Adjustment Cost Rationalization of Asset Fixity Theory. *American Journal of Agricultural Economics* 72: 298-308.

Hubbard, R.G. and Kashyap, A.K. (1992). Internal Net Worth and the Investment Process: An Application to U.S. Agriculture. *Journal of Political Economy* 100: 506-534.

Ivaldi, M., Ladoux, N., Ossard, H. and Simioni, M. (1996). Comparing Fourier and Translog Specifications of Multiproduct Technology: Evidence from an incomplete panel of French farmers. *Journal of Applied Econometrics* 11: 649-667.

Johnson, G.L. (1956). Supply Functions – Some Facts and Notions. In Heady, E. (ed.), *Agricultural Adjustment Problems in a Growing Economy*. Iowa State University Press.

Judge, G.G., Griffiths, W.E., Hill, R.C., Lütkepohl, H. and Lee, T.C. (1985). *The Theory and Practice of Econometrics*. Second edition. New York: John Wiley and Sons.

Kalirajan, K.P., Obwona, M.B. and Zhao, S. (1996). A decomposition of total factor productivity growth: The case of Chinese agricultural growth before and after reforms. *American Journal of Agricultural Economics* 78: 331-338.

Kohli, U. (1993). A Symmetric Normalised Quadratic GNP function and the U.S. demand for imports and supply of exports. *International Economic Review* 34: 243-255.

LEI (2000). *Landbouw-Economisch Bericht 2000*. Den Haag.

LEI/Statistics Netherlands (several years). *Land- en tuinbouwcijfers*. Den Haag/ Voorburg.

Lucas, R.E. (1976). Econometric policy evaluation: a critique. In Brunner, K. and Meltzer, A. (eds.) *The Phillips Curve and Labour Markets*. Carnegie-Rochester Conference Series 1, 19-46.

Luh,Y.H. and Stefanou, S.E. (1996) Estimating Dynamic Dual Models under Nonstatic Expectations. *American Journal of Agricultural Economics* 78: 991-1003.

Maddala, G.S. (1987). Limited dependent variable models using panel data. *Journal of Human Resources* 22: 307-338.

Magnus, J.R. (1978). Maximum Likelihood estimation of the GLS model with unknown parameters in the disturbance covariance matrix. *Journal of Econometrics* 7: 281-312.

Mátyás, L. (1999). *Generalized Method of Moments Estimation*. Cambridge: Cambridge University Press.

Meester, G. (1995). Sociaal-wetenschappelijk onderzoek en beleid. *Tijdschrift voor Sociaal Wetenschappelijk onderzoek in de Landbouw* 10: 268-279.

Ministerie van Landbouw, Natuurbeheer en Visserij (LNV, 1996). *Evaluatie Wet verplaatsing mestproduktie*. Den Haag.

Ministerie van Landbouw, Natuurbeheer en Visserij (LNV, 1998). *Wet herstructurering varkenshouderij*. Den Haag. Internet: http://www.minlnv.nl/herstructurering/

Ministerie van Landbouw, Natuurbeheer en Visserij (LNV, 2000). *Het mineralenaangifte-systeem MINAS*. Den Haag. Internet: http://www.minlnv.nl/minas/

Mittelhammer, R.C., Judge, G.G. and Miller, D.J. (2000). *Econometric Foundations.* Cambridge: Cambridge University Press.

Moschini, G. (1988). A Model of Production with Supply Management for the Canadian Agricultural Sector. *American Journal of Agricultural Economics* 70: 318-329.

Mulder, M. (1994). *Bedrijfstakverkenning en financiële analyse. Een simulatiemodel voor de glastuinbouw*. LEI Onderzoekverslag 126. Den Haag: LEI.

Mundlak, Y. (1961). Empirical production function free of management bias. *Journal of Farm Economics* 43: 44-56.

Muller, J. (1974). On sources of measured technical efficiency: The impact of information. *American Journal of Agricultural Economics* 56: 730-738.

Mussa, M. (1977). External and Internal Adjustment Costs and the Theory of Aggregate and Firm Investment. *Econometrica* 44: 163-178.

Nickell, S. (1978). *The investment decisions of firms.* Cambridge: Cambridge University Press.

Nuthall, P.L. (2001). Managerial ability – a review of its basis and potential improvement using psychological concepts. *Agricultural Economics* 24: 247-262.

Ogaki, M. (1999). GMM Estimation Techniques. In Mátyás, L. (ed.), *Generalized Method of Moments Estimation*. Cambridge: Cambridge University Press, 31-62.

Oude Lansink, A. (2000). Productivity growth and efficiency measurement: a dual approach. *European Review of Agricultural Economics* 27: 59-73.

Oude Lansink, A. and Stefanou, S.E. (1997). Asymmetric Adjustment of Dynamic Factors at the Firm Level. *American Journal of Agricultural Economics* 79: 1340-1351.

Oude Lansink, A. and Thijssen, G. (1998). Testing among functional forms: an extension of the Generalized Box-Cox formulation. *Applied Economics* 30: 1001-1010.

Pesaran, M.H. (1987). *The Limits to Rational Expectations*. Oxford: Basil Blackwell.

Pfann, G.A. and Palm, F.C. (1993). Asymmetric Adjustment Costs in Non-linear Labour Demand Models for the Netherlands and U.K. Manufacturing Sectors. *Review of Economic Studies* 60: 397-412.

Pietola, K.S. and Myers, R.J. (2000). Investment Under Uncertainty and Dynamic Adjustment in the Finnish Pork Industry. *American Journal of Agricultural Economics* 82: 956-967.

Pietola, K.S. and Oude Lansink, A.G.J.M. (2001). A choice between standard and organic farming technologies in Finland. *European Review of Agricultural Economics* 28. forthcoming.

Pindyck, R.S. and Rotemberg, J.J. (1983). Dynamic Factor Demands and the Effects of Energy Price Shocks. *American Economic Review* 73: 1066-1079.

Price, T.J. and Wetzstein, M.E. (1998). Irreversible Investment Decisions in Perennial Crops with Yield and Price Uncertainty. *Journal of Agricultural and Resource Economics* 24: 173-185.

Richards, T.J. and Jeffrey, S.R. (1997). The effect of Supply Management on Herd Size in Alberta Dairy. *American Journal of Agricultural Economics* 79: 555-565.

Rothschild, M. (1971). On the Cost of Adjustment. *Quarterly Journal of Economics* 75: 605-622.

Rougoor, C.W., Trip, G., Huirne, R.B.M. and Renkema, J.A. (1998). How to define and study farmers' management capacity: theory and use in agricultural economics. *Agricultural Economics* 18: 261-272.

Rucker, R.R., Thurman, W.N. and Sumner, D.A. (1995). Restricting the Market for Quota: An Analysis of Tobacco Production Rights with Corroboration from Congressional Testimony. *Journal of Political Economy* 103: 142-175.

Rust, J. (1996). Numerical dynamic programming in economics. In Amman, H.M., Kendrick, D.A. and Rust, J. (eds.), *Handbook of Computational Economics*, Volume 1, Amsterdam: Elsevier, 619-729.

Segerson, K. and Squires, D. (1993). Capacity Utilization under Regulatory Constraints. *Review of Economics and Statistics* 75: 76-85.

Shapiro, M.D. (1986). The Dynamic Demand for Capital and Labor. *Quarterly Journal of Economics* 101: 513-542.

Stefanou, S.E. (1995). Anticipating a Production Quota and Investment. *Rivista Internazionale di Scienze Economiche e Commerciali* 42: 301-314.

Stefanou, S.E., Fernandez-Cornejo, J., Gempesaw II, C.M. and Elterich, J.G. (1992). Dynamic structure of production under a quota: The case of milk production in the Federal Republic of Germany. *European Review of Agricultural Economics* 19: 283-299.

Thijssen, G.J. (1992). Supply Response and Input Demand of Dutch Dairy Farms. *European Review of Agricultural Economics* 19: 219-235.

Thijssen, G.J. (1996). Farmers' Investment Behavior: An Empirical Assessment of Two Specifications of Expectations. *American Journal of Agricultural Economics* 78: 166-147.

Varian, H.R. (1992). *Microeconomic Analysis*. Third edition. New York: W.W. Norton & Company.

Vasavada, U. and Chambers, R.G. (1986). Investment in U.S. Agriculture. *American Journal of Agricultural Economics* 68: 950-960.

Verbeek, M. and Nijman, T.E. (1992a). Incomplete panels and selection bias. In Mátyás, L. and Sevestre, P. (eds.), *The econometrics of panel data: handbook of theory and applications*. Dordrecht: Kluwer Academic Publishers, 262-302.

Verbeek, M. and Nijman, T.E. (1992b). Testing for selectivity bias in panel data models. *International Economic Review* 33: 681-703

Verstegen, J.A.A.M., Huirne, R.B.M., Dijkhuizen, A.A. and King, R.P. (1995). Quantifying Economic Benefits of Sow-Herd Management Information Systems Using Panel Data. *American Journal of Agricultural Economics* 77: 387-396.

Whited, T.M. (1992). Debt, Liquidity Constraints and Corporate Investment: Evidence from Panel Data. *Journal of Finance* 47: 1425-1460.

Whited, T.M. (1998). Why Do Investment Euler Equations Fail? *Journal of Business and Economic Statistics* 16: 479-488.

Wiley, D.E., Schmidt, W.H. and Bramble, W.J. (1973). Studies of a Class of Covariance Structure Models. *Journal of the American Statistical Association* 68: 317-323.

Winter, J. (1998). *Investment and exit decisions at the plant level: a dynamic programming approach.* Heidelberg: Physica verlag.

APPENDICES

Appendix I Tables used in chapter two

The data used in this thesis were made available under certain conditions by the Dutch Agricultural Economics Research Institute (LEI). In order to safeguard the confidentiality of the individual farmers in the dataset, it is not allowed to publish data on individual farms. In order to give some background information on the data, table I.1 gives the means and standard deviations of the variables used in chapter two.

Table I.1 Mean and standard deviation of variables used in chapter two

Variable	Dimension/Base year	Symbol	Mean	Standard Deviation
Price indices				
Pig output	Base year 1980	p_1	1.079	0.181
Pig feed	Base year 1980	p_2	0.927	0.106
Other variable input	Base year 1980	p_3	1.065	0.051
Quantities				
Pig Output	100.000 Dutch guilders of 1980	q_1	5.356	4.190
Pig feed	100.000 Dutch guilders of 1980	q_2	-2.890	2.126
Other variable inputs	100.000 Dutch guilders of 1980	q_3	-1.179	0.996
Farm family labour	1000 hours	z_1	3.305	1.175
Capital in Buildings	100.000 Dutch guilders of 1980	z_2	4.404	3.397
Capital in Machinery	100.000 Dutch guilders of 1980	z_3	0.547	0.548
Land	Hectares	z_4	6.979	7.256
Technological change	Trend, 1980=1	z_5	9.654	4.760
Region East	Dummy, east=1 other=0	z_6	0.418	0.494
Region West	Dummy, south=1 other=0	z_7	0.459	0.499

Period: 1980-1996.
Observations: 735

Table I.2 Parameter estimates for different estimators ((corrected) standard errors in parentheses).*

Parameter	Fixed effects*	Random effects	Hausman-Taylor
α_1		1.409 (0.737)	1.645 (0.745)
α_2		-0.424 (0.444)	-0.541 (0.448)
α_3		-0.124 (0.219)	-0.201 (0.221)
α_{11}	-0.109 (0.136)	-0.040 (0.129)	-0.083 (0.130)
α_{12}	0.183 (0.104)	0.138 (0.098)	0.161 (0.099)
α_{22}	-0.057 (0.132)	-0.044 (0.125)	-0.054 (0.125)
β_{11}	-0.032 (0.055)	-0.034 (0.046)	-0.050 (0.047)
β_{12}	0.128 (0.022)	0.093 (0.019)	0.112 (0.020)
β_{13}	-0.208 (0.153)	-0.190 (0.138)	-0.223 (0.145)
β_{14}	0.005 (0.009)	0.007 (0.008)	0.007 (0.008)
β_{15}	0.032 (0.012)	0.019 (0.010)	0.018 (0.010)
β_{16}	-0.436 (0.267)	-0.337 (0.221)	-0.380 (0.225)
β_{17}	-0.234 (0.253)	-0.091 (0.214)	-0.112 (0.218)
β_{22}	0.028 (0.013)	-0.018 (0.009)	0.024 (0.011)
β_{23}	-0.192 (0.079)	-0.096 (0.046)	-0.142 (0.063)
β_{24}	-0.005 (0.005)	-0.007 (0.003)	-0.007 (0.004)
β_{25}	0.003 (0.007)	-0.003 (0.005)	-0.002 (0.006)
β_{26}	-0.053 (0.206)	-0.019 (0.126)	-0.050 (0.145)
β_{27}	-0.096 (0.205)	-0.080 (0.124)	-0.098 (0.142)
β_{33}	0.948 (0.463)	0.243 (0.181)	0.572 (0.338)
β_{34}	0.005 (0.026)	0.236 (0.018)	0.023 (0.021)
β_{35}	0.085 (0.044)	0.063 (0.031)	0.068 (0.037)
β_{36}	0.904 (0.816)	0.643 (0.718)	0.770 (0.759)
β_{37}	0.161 (0.794)	0.328 (0.694)	0.203 (0.740)
β_{44}	-0.001 (0.002)	-0.001 (0.001)	-0.001 (0.001)
β_{45}	0.003 (0.002)	0.003 (0.002)	0.004 (0.002)
β_{46}	0.098 (0.057)	0.062 (0.038)	0.067 (0.038)
β_{47}	0.081 (0.056)	0.065 (0.037)	0.070 (0.038)
β_{55}	0.000 (0.004)	0.000 (0.003)	0.000 (0.003)
β_{56}	-0.016 (0.052)	-0.012 (0.039)	-0.010 (0.039)
β_{57}	-0.045 (0.052)	-0.042 (0.039)	-0.041 (0.040)
γ_{11}	-0.065 (0.185)	0.081 (0.159)	-0.093 (0.162)
γ_{12}	0.270 (0.128)	0.405 (0.088)	0.333 (0.098)
γ_{13}	-0.466 (0.556)	-0.227 (0.489)	-0.354 (0.518)
γ_{14}	0.042 (0.041)	0.046 (0.029)	0.044 (0.029)
γ_{15}	0.053 (0.041)	0.089 (0.033)	0.088 (0.034)
γ_{16}		0.013 (0.800)	0.239 (0.810)
γ_{17}		-0.408 (0.786)	-0.237 (0.798)
γ_{21}	-0.153 (0.093)	-0.190 (0.080)	-0.183 (0.081)
γ_{22}	-0.374 (0.061)	-0.382 (0.043)	-0.378 (0.048)
γ_{23}	0.281 (0.267)	0.207 (0.234)	0.307 (0.249)
γ_{24}	-0.058 (0.020)	-0.058 (0.015)	-0.056 (0.015)
γ_{25}	-0.076 (0.020)	-0.075 (0.017)	-0.072 (0.017)
γ_{26}		0.291 (0.480)	0.285 (0.485)
γ_{27}		0.451 (0.471)	0.435 (0.476)
γ_{31}	-0.004 (0.045)	0.010 (0.039)	0.010 (0.039)
γ_{32}	-0.135 (0.029)	-0.138 (0.021)	-0.127 (0.023)
γ_{33}	0.165 (0.129)	0.112 (0.113)	0.174 (0.120)
γ_{34}	-0.056 (0.010)	-0.056 (0.007)	-0.056 (0.007)
γ_{35}	-0.060 (0.010)	-0.056 (0.008)	-0.054 (0.008)
γ_{36}		0.063 (0.237)	0.042 (0.239)
γ_{37}		0.194 (0.232)	0.175 (0.235)

* Standard errors are corrected for degrees of freedom (Greene, 1997:617).

Appendix II Tables used in chapter three

Table II.1. Mean and standard deviation of variables used in chapter three

Variable	Dimension/Base year	Symbol	Mean	Standard Deviation
Price indices				
Pig output	Base year 1980	v_1	1.035	0.058
Pig feed	Base year 1980	v_2	0.906	0.086
Other variable input	Base year 1980	v_3	1.041	0.138
Quantities				
Pig Output	100.000 guilders of 1980	q_1	5.104	3.788
Pig feed	100.000 guilders of 1980	q_2	-2.797	1.982
Other variable inputs	100.000 guilders of 1980	q_3	-1.124	0.919
Farm family labour	1000 hours	z_1	3.295	1.177
Capital in Buildings	100.000 guilders of 1980	z_2	4.331	3.217
Capital in Machinery	100.000 guilders of 1980	z_3	0.538	0.542
Land	hectares	z_4	6.787	6.840
Technological change	Trend, 1980=1	z_5	9.153	4.501

Period: 1980-1995.
Observations: 688

Table II.2 Parameter estimates for pig breeding farms (corrected t-ratio's in parentheses).*

Parameter	Estimate		Parameter	Estimate	
α_{11}	0.236	(2.283)	γ_{11}	-0.302	(-2.455)
α_{12}	-0.075	(-0.937)	γ_{12}	0.225	(3.644)
α_{22}	0.109	(0.869)	γ_{13}	-0.484	(-1.453)
β_{11}	0.015	(0.426)	γ_{14}	0.024	(0.823)
β_{12}	0.119	(7.904)	γ_{15}	0.108	(3.908)
β_{13}	-0.086	(-0.821)	γ_{21}	-0.257	(-4.526)
β_{14}	0.014	(1.963)	γ_{22}	-0.305	(-10.633)
β_{15}	0.026	(3.008)	γ_{23}	-0.057	(-0.367)
β_{22}	-0.008	(-0.823)	γ_{24}	-0.048	(-3.480)
β_{23}	0.014	(0.280)	γ_{25}	-0.051	(-3.961)
β_{24}	0.002	(0.557)	γ_{31}	-0.085	(-2.935)
β_{25}	0.002	(0.404)	γ_{32}	-0.104	(-7.047)
β_{33}	0.287	(1.020)	γ_{33}	0.064	(0.831)
β_{34}	0.012	(0.615)	γ_{34}	-0.052	(-7.323)
β_{35}	0.013	(0.394)	γ_{35}	-0.049	(-7.118)
β_{44}	0.002	(1.088)			
β_{45}	0.001	(0.674)			
β_{55}	-0.007	(-2.671)			

* Standard errors are corrected for degrees of freedom (Greene, 1997:617).

Appendix III Tables used in chapter four

Table III.1 Mean and standard deviation of variables used in chapter four

Variable	Dimension/Base year	Symbol	Mean	Standard Deviation
Quantities				
Investment buildings	100.000 Dutch guilders of 1980	I_1	0.361	0.984
Investment machinery	100.000 Dutch guilders of 1980	I_2	0.095	0.173
Buildings	100.000 Dutch guilders of 1980	x_1	5.054	3.197
Machinery	100.000 Dutch guilders of 1980	x_2	0.682	0.612
Pig feed	100.000 Dutch guilders of 1980	x_3	4.321	3.199
Other variable input	100.000 Dutch guilders of 1980	x_4	1.257	1.040
Farm family labour	1000 hours	x_5	3.481	1.367
Land	Hectares	x_6	8.177	8.989
Technological change	Trend, 1980=1	x_7	9.897	4.612
Price indices				
Purchase price buildings	Base year 1980	p_1	1.036	0.056
Purchase price machinery	Base year 1980	p_2	2.443	0.682
Pig output	Base year 1980	p	1.077	0.191

Period: 1980-1996.
Observations: 1430

Table III.2 Probit estimates for investment in buildings and machinery in two consecutive periods, $D_{ht+1} = 1$*, (standard errors in parentheses)*

Buildings		Machinery	
Variable	Estimate	Variable	Estimate
$I_{1,t-1}$	0.153 (0.061)**	$I_{2,t-1}$	1.053 (0.401)**
$p_{1,t-1}$	-0.493 (0.583)	$p_{2,t-1}$	-0.035 (0.194)
p_{t-1}	-0.404 (0.378)	p_{t-1}	-0.654 (0.249)**
$x_{1,t-1}$	-0.090 (0.052)*	$x_{1,t-1}$	0.071 (0.056)
$x_{2,t-1}$	-0.156 (0.181)	$x_{2,t-1}$	0.282 (0.250)
$x_{3,t-1}$	-0.008 (0.044)	$x_{3,t-1}$	-0.076 (0.054)
$x_{4,t-1}$	0.013 (0.163)	$x_{4,t-1}$	0.091 (0.197)
$x_{5,t-1}$	0.141 (0.062)*	$x_{5,t-1}$	0.127 (0.069)*
$x_{6,t-1}$	-0.021 (0.013)**	$x_{6,t-1}$	0.050 (0.017)**
$x_{7,t-1}$	-0.014 (0.023)	$x_{7,t-1}$	-0.002 (0.039)
age_{t-1}	-0.012 (0.006)**	age_{t-1}	-0.004 (0.005)
$succ_{t-1}$	0.019 (0.098)	$succ_{t-1}$	0.016 (0.098)
dar_{t-1}	0.160 (0.167)	dar_{t-1}	0.959 (0.166)**
eqc_{t-1}	-0.144 (0.085)*	eqc_{t-1}	-0.200 (0.100)**
int_{t-1}	1.502 (0.613)**	int_{t-1}	-0.412 (0.640)
inc_{t-1}	0.183 (0.078)**	inc_{t-1}	0.514 (0.096)**
$I_{1,t-2}$	0.082 (0.072)	$I_{2,t-2}$	0.434 (0.471)
$p_{1,t-2}$	1.474 (0.610)**	$p_{2,t-2}$	0.426 (0.241)*
p_{t-2}	-0.874 (0.381)**	p_{t-2}	-0.448 (0.269)*
$x_{1,t-2}$	0.103 (0.051)**	$x_{1,t-2}$	0.009 (0.053)
$x_{2,t-2}$	-0.327 (0.249)	$x_{2,t-2}$	-0.034 (0.325)
$x_{3,t-2}$	-0.043 (0.063)	$x_{3,t-2}$	-0.017 (0.078)
$x_{4,t-2}$	-0.199 (0.261)	$x_{4,t-2}$	-0.190 (0.315)
$x_{5,t-2}$	-0.004 (0.093)	$x_{5,t-2}$	0.109 (0.096)
$x_{6,t-2}$	0.020 (0.018)	$x_{6,t-2}$	-0.014 (0.023)
$x_{7,t-2}$	-0.066 (0.032)**	$x_{7,t-2}$	-0.071 (0.053)
$I_{1,t-3}$	0.010 (0.095)	$I_{2,t-3}$	0.226 (0.578)
$p_{1,t-3}$	-0.110 (0.741)	$p_{2,t-3}$	0.236 (0.280)
p_{t-3}	0.205 (0.526)	p_{t-3}	-0.079 (0.303)
$x_{1,t-3}$	-0.079 (0.049)	$x_{1,t-3}$	-0.054 (0.052)
$x_{2,t-3}$	0.141 (0.227)	$x_{2,t-3}$	0.025 (0.297)
$x_{3,t-3}$	-0.006 (0.064)	$x_{3,t-3}$	-0.015 (0.075)
$x_{4,t-3}$	0.230 (0.260)	$x_{4,t-3}$	0.278 (0.302)
$x_{5,t-3}$	0.017 (0.094)	$x_{5,t-3}$	-0.187 (0.095)**
$x_{6,t-3}$	-0.020 (0.018)	$x_{6,t-3}$	0.018 (0.023)
$x_{7,t-3}$	0.004 (0.033)	$x_{7,t-3}$	-0.016 (0.061)
McFadden's R^2	0.09	McFadden's R^2	0.17
Count R^2	0.71	Count R^2	0.73

** Significantly different from zero at the 5% level
* Significantly different from zero at the 10% level

Appendix IV Tables used in chapter five

Table IV.1 Mean and standard deviation of variables used in chapter five

Variable	Dimension/Base year	Symbol	Mean	Standard Deviation
Quantities				
Capital investment	100.000 Dutch guilders of 1980	I	0.515	1.095
Capital	100.000 Dutch guilders of 1980	x_1	5.673	4.093
Pig feed	100.000 Dutch guilders of 1980	x_2	4.479	3.198
Other variable input	100.000 Dutch guilders of 1980	x_3	1.320	1.021
Farm family labour	1000 hours	x_4	3.465	1.356
Land	Hectares	x_5	8.470	9.767
Technological change	Trend, 1980=1	x_6	10.921	4.226
Price indices				
Capital	Base year 1980	p^I	1.239	0.101
Pig output	Base year 1980	p	1.069	0.191

Period: 1980-1996.
Observations: 882

Table IV.2 Probit estimates for capital adjustment in two consecutive periods, $D_{ht+1} = \Gamma(I_{ht+1} \cdot I_{ht} \neq 0) = 1$, standard errors in parentheses)

Variable	Estimate	Variable	Estimate
I_{t-1}	0.355 (0.093)*	$x_{3,t-2}$	0.018 (0.309)
p^I_{t-1}	0.075 (0.477)	$x_{4,t-2}$	0.097 (0.110)
p_{t-1}	-0.352 (0.309)	$x_{5,t-2}$	-0.027 (0.024)
$x_{1,t-1}$	0.035 (0.037)	$x_{6,t-2}$	-0.047 (0.039)
$x_{2,t-1}$	0.014 (0.051)	I_{t-3}	0.186 (0.108)
$x_{3,t-1}$	0.068 (0.190)	p^I_{t-3}	0.911 (0.726)
$x_{4,t-1}$	0.158 (0.072)*	p_{t-3}	-0.588 (0.498)
$x_{5,t-1}$	0.041 (0.015)*	$x_{1,t-3}$	-0.022 (0.049)
$x_{6,t-1}$	-0.001 (0.027)	$x_{2,t-3}$	0.060 (0.071)
I_{t-2}	0.301 (0.111)*	$x_{3,t-3}$	-0.110 (0.316)
p^I_{t-2}	0.913 (0.618)	$x_{4,t-3}$	-0.135 (0.105)
p_{t-2}	-0.878 (0.370)*	$x_{5,t-3}$	0.022 (0.023)
$x_{1,t-2}$	-0.012 (0.053)	$x_{6,t-3}$	-0.009 (0.040)
$x_{2,t-2}$	-0.036 (0.075)		
McFadden's R^2	0.12		
Count R^2	0.75		

* Significant at the 5% level

SUMMARY

Farmers operate their business in a dynamic environment. Fluctuating prices, evolving agricultural and environmental policies, technological change and increasing consumer demands for product quality (e.g. with respect to environmental friendly production methods, animal welfare and food safety) frequently require adjustment of production and input levels on individual farms. Quantities of variable production factors like animal feed or pesticides can usually be adjusted easily together with changing production levels. Quantities of labour, capital and land however, are less easy to adjust. Instantaneous adjustment may be impossible or imply (high) costs of adjustment. In the long run, quantities of these quasi-fixed factors can be adjusted at lower costs of adjustment.

The Dutch pig sector is an interesting case for studying adjustment of quasi-fixed factors. Increases in the average farm size, accompanied by an ongoing specialisation, implied considerable adjustments for individual farms. Moreover, environmental legislation has had a significant impact on pig production, providing another reason to study adjustment behaviour of Dutch pig farms.

Understanding the process of adjustment of quasi-fixed factors is important for a number of reasons. First, it shows how farmers reorganise their production in the long run as a reaction to changes in the economic environment, e.g. a decrease in output prices. Second, understanding adjustment of quasi-fixed factors may explain farmers' entry and exit decisions. Third, knowledge about long run adjustment processes at the farm level can be used in economic models to simulate long-term effects of agricultural and environmental policies on individual farms.

The objective of this thesis is to study capital adjustment at individual pig farms in the Netherlands, taking farm-specific characteristics into account. In order to study this process, micro-economic models are constructed and estimated. From this broad objective, four specific objectives are defined and worked out in individual chapters.

In chapter two the relation between unobserved farm-specific effects, accounting for differences in management, and quasi-fixed factors (e.g. capital) is investigated for specialised pig breeding farms for the period 1980-1996. Managerial ability is often seen as a major determinant in pig production and as an important source of farm heterogeneity. Technical skills and skills in organising the production process, which are both considered to be elements of an aggregate management variable, not only have a direct impact on production and profits, but also interact with other production factors. In order to investigate

the relation between the farm-specific effects and quasi-fixed factors, a system of output supply and input demand equations is estimated using the Hausman-Taylor panel data estimator. This estimator has a number of advantages over other estimation methods and allows for performing tests on correlation of different sets of explanatory variables with the farm-specific effects, thereby yielding insight in the unobserved management variable and its relation to quasi-fixed factors in pig production. Testing indicates that farm-specific effects in a system of output supply and input demand equations for Dutch pig breeding farms are correlated with buildings and machinery and installations. Therefore, it can be concluded that differences in management are related to different quantities of these capital goods. Results indicate that pig farms with good management have more buildings and machinery than pig farms with poor management. Although the correlation between management and the quantity of capital does not imply a direct causal relationship, it can be inferred that either good management is a major determinant in capital investment or that a large capital base enables a pig farmer to improve upon its management skills.

Although farmers cannot adjust the quantities of the quasi-fixed factors in the short run, sometimes they utilise only part of the available quantities. For example when supply quotas are introduced and the restricted quota quantities are well below the optimal production levels, farmers may be forced to reduce the utilisation of the available quasi-fixed factors in the short run. Chapter three develops a theoretical model to analyse the short-run effects of factor under-utilisation on the shadow price of production and the shadow price of supply quotas. In the theoretical model it is shown that ignoring under-utilisation leads to overestimation of the shadow prices of quota rights. The model is used to simulate prices of pig rights for pig breeding farms introduced by the 1998 pig sector restructuring law with and without taking factor under-utilisation into account. Simulation results show that ignoring factor under-utilisation in this case overestimates quota prices on average by approximately 24%. For the Dutch government buying out pig production rights, overestimation of the price of pig production rights leads to budget costs that are too high. Taking under-utilisation into account implies that compensation for bought out production rights should be lower. With tradable quotas, factor under-utilisation implies that farmers are less willing to buy additional pig production rights.

Where chapter three considers the utilisation of available quasi-fixed factors in the short-run, chapter four explicitly looks at adjustment of quantities of buildings and machinery. An investment model for Dutch pig farmers is specified and estimated for buildings and machinery. This investment model integrates two existing investment theories, i.e. fixed asset theory and adjustment cost theory, in one coherent framework. Fixed asset theory states that thresholds exists for investment, thus providing a theoretical motivation for observed zero investments. Adjustment cost theory motivates spreading of investments over time by posing that farms incur increasing costs in adjusting their capital stocks. In the model it is assumed that farmers have different thresholds for investment. Alternative specifications for the adjustment cost functions of buildings and machinery are tested for. Writing the investment problem as a long-run optimisation problem, optimality conditions are derived and estimated for different investment regimes. Estimation and testing results indicate that adjustment costs are important determinants in investment for buildings but not for machinery. This implies that when farmers adjust the stock of machinery, this adjustment is instantaneous. Furthermore, testing indicates that joint farm-specific parameters, which include farm-specific thresholds for investment and other farm-specific effects, are present in the optimality conditions for investment. However, these farm-specific investment thresholds cannot be calculated since they cannot be separated from other elements in the joint farm-specific parameters.

Quantitative restrictions on production may not only lead to lower utilisation of capital in the short run as discussed before, they may also reduce investment in the long run. Consequences of lower investments are that innovation is reduced, deteriorating the long-run productivity of the sector and that investments contributing to the solution of the manure problem are lower. Using the investment model developed in chapter four, chapter five tests for the impact of manure production rights on capital investment of Dutch pig farms for the period 1987-1996. Manure production rights were introduced in 1987. Given the close relationship between pig production and manure production, a system of manure production rights also implies a constraint on pig production. However, thus far it is not well understood whether investments were reduced by this implicit output constraint or not. In the theoretical model it is shown that a constraint on production implies a reduction in investment. A testing procedure, based on a GMM structural break test, is developed and implemented. The results provide evidence for a negative impact of manure production rights on investment after 1987. Lower investments in the period after 1987 may have weakened the future viability of the pig sector.

Chapter six summarises the main conclusions and discusses two main aspects of this thesis, i.e. theories of long-run adjustment of quasi-fixed factors and taking farm heterogeneity into account using panel data techniques. This chapter ends with suggestions for future research.

SAMENVATTING (Summary in Dutch)

Agrarische bedrijven opereren in een dynamische omgeving. Fluctuerende prijzen, veranderingen in het landbouw- en milieubeleid, technologische vooruitgang en de groeiende vraag van consumenten naar o.a. milieuvriendelijke productiemethoden, dierwelzijn en voedselveiligheid vragen voortdurend om aanpassing van het productieniveau en de hoeveelheid ingezette productiemiddelen op individuele landbouwbedrijven. De productie en de hoeveelheden van variabele productiemiddelen zoals diervoeders kunnen doorgaans eenvoudig aangepast worden. De zogenaamde quasi-vaste productiemiddelen arbeid, kapitaal en land zijn echter minder gemakkelijk aan te passen. Directe aanpassing is veelal onmogelijk of leidt tot hoge aanpassingskosten. Op lange termijn zijn deze aanpassingkosten veelal lager en passen ook deze productiemiddelen zich aan.

Er zijn een aantal redenen om het aanpassingsproces van quasi-vaste productiemiddelen op bedrijfsniveau te bestuderen. Ten eerste laat het zien hoe boeren hun productie op lange termijn aanpassen als reactie op veranderingen in de economische omgeving zoals bijvoorbeeld een prijsdaling. Ten tweede geeft het inzicht in beslissingen omtrent het stoppen of opstarten van een bedrijf. Ten derde kan deze kennis gebruikt worden in economische simulatie modellen om de lange termijn effecten van landbouw- en milieubeleid te bepalen voor individuele bedrijven. De Nederlandse varkenshouderij is een interessante sector om aanpassingen van quasi-vaste productiemiddelen te bestuderen. De toename van de gemiddelde bedrijfsgrootte, de voortgaande specialisatie en de grote invloed van landbouw- en milieubeleid in de afgelopen decennia hebben tot aanzienlijke veranderingen geleid op individuele varkensbedrijven.

Het doel van dit proefschrift is het bestuderen van aanpassingen in de kapitaalgoederenvoorraad van individuele varkensbedrijven in Nederland, waarbij rekening wordt gehouden met bedrijfsspecifieke factoren. Om dit aanpassingsproces te bestuderen zijn micro-economische modellen geformuleerd en geschat met behulp van econometrische technieken. Vanuit deze brede doelstelling zijn vier specifieke doelstellingen geformuleerd die in aparte hoofdstukken zijn uitgewerkt.

Hoofdstuk twee onderzoekt de relatie tussen bedrijfsspecifieke factoren en de hoeveelheid ingezette quasi-vaste productiemiddelen (waaronder kapitaalgoederen) voor gespecialiseerde fokvarkensbedrijven in de periode 1980-1996. Verschillen in management vormen een aanzienlijk deel van deze bedrijfsspecifieke factoren. Management, bestaand uit technische vaardigheden en vaardigheden in het organiseren van het productieproces, is een belangrijke factor in de productie van varkens en is een bron van heterogeniteit tussen bedrijven. Management heeft echter niet alleen een directe invloed op productie en bedrijfsopbrengsten. Er is ook interactie met andere productiemiddelen. Om de relatie tussen bedrijfsspecifieke factoren en de hoeveelheid ingezette quasi-vaste productiemiddelen te onderzoeken, worden een aanbodsvergelijking en een aantal vraagvergelijkingen voor variabele productiemiddelen geschat met de zogenaamde Hausman-Taylor panel data schattingsmethode. Deze methode heeft een aantal voordelen ten opzichte van andere schattingsmethoden en maakt het mogelijk om te testen of bepaalde quasi-vaste productiemiddelen samenhangen met de bedrijfsspecifieke factoren. Dit geeft inzicht in de management variabele en haar relatie met quasi-vaste productiemiddelen. De testuitkomsten geven aan dat in dit systeem van vergelijkingen voor Nederlandse fokvarkensbedrijven de bedrijfsspecifieke factoren samenhangen met de hoeveelheden van gebouwen en machines en installaties. De conclusie is dat verschillen in management samenhangen met verschillen in de hoeveelheden van deze kapitaalgoederen. Fokvarkensbedrijven met goed management hebben doorgaans meer gebouwen en machines dan bedrijven met minder goed management. Alhoewel deze samenhang niet direct een causaal verband impliceert, kan dit betekenen dat goed management een belangrijke verklarende variabele voor investeren is òf dat een grote hoeveelheid van deze kapitaalgoederen de boer in staat stelt tot het verbeteren van zijn (management) vaardigheden.

Omdat boeren de hoeveelheden van quasi-vaste productiemiddelen op korte termijn niet aan kunnen passen, wordt soms slechts een deel van de aanwezige hoeveelheid benut, bijvoorbeeld wanneer productiequota worden ingevoerd. Hoofdstuk drie ontwikkelt een theoretisch model om de korte termijn effecten van deze onderbenutting te bepalen voor de schaduwprijs van productierechten. De schaduwprijs is de waarde van een extra eenheid productierecht voor het bedrijf en geeft dus de prijs die een boer maximaal zou willen betalen voor zo’n extra eenheid. Tevens geeft het de prijs die de boer minimaal wil ontvangen als hij besluit een eenheid productierecht te verkopen. Het model laat zien dat het negeren van onderbenutting leidt tot een overschatting van de schaduwprijzen van productierechten. Vervolgens is het model gebruikt om de schaduwprijzen van fokzeugenrechten te bepalen met en zonder onderbenutting. Fokzeugenrechten werden geïntroduceerd met de Herstructureringswet die in 1998 is ingevoerd. De simulatieresultaten laten zien dat het negeren van onderbenutting leidt tot een overschatting van schaduwprijzen van gemiddeld 24%. Voor de Nederlandse overheid die varkensboeren uitkoopt en een vergoeding geeft voor de aanwezige varkensrechten zal een overschatting leiden tot te hoge uitgaven. Als productierechten verhandelbaar zijn betekent rekening houden met onderbenutting dat boeren minder geneigd zullen zijn extra productierechten te kopen.

Analyseert hoofdstuk drie de benutting van de aanwezige quasi-vaste productiemiddelen op korte termijn, hoofdstuk vier kijkt expliciet naar aanpassingen in de hoeveelheden gebouwen en machines. Een investeringsmodel voor Nederlandse varkenshouders is gespecificeerd en (econometrisch) geschat voor deze kapitaalgoederen. Dit model integreert twee bestaande investeringstheorieën, namelijk de ‘fixed asset’ theorie en de aanpassingskostentheorie. De ‘fixed asset’ theorie zegt dat er drempels voor investeringen bestaan en geeft zo een theoretische verklaring voor nulinvesteringen die er veelal zijn op bedrijfsniveau. De aanpassingskostentheorie zegt dat aanpassingen (investeringen) doorgaans traag en gespreid verlopen vanwege aanpassingskosten die groter zijn naarmate de investering omvangrijker is. In het ontwikkelde model wordt verondersteld dat bedrijven verschillende drempels voor investeringen hebben. Tevens hebben bedrijven verschillende aanpassingskosten voor een gegeven investering. Door het investeringsprobleem te definiëren als een lange termijn optimalisatieprobleem kunnen condities voor een optimum wiskundig worden afgeleid voor verschillende investeringsregimes van gebouwen en machines. Deze condities die noodzakelijk zijn voor een optimum worden vervolgens geschat. Voor beide kapitaalgoederen zijn verschillende specificaties voor de aanpassingskostenfunctie getest. De resultaten van het schatten en testen wijzen erop dat aanpassingskosten belangrijk zijn voor investeringen in gebouwen maar niet voor machines. Investeren boeren in machines, dan is er geen reden deze investeringen gespreid te laten plaatsvinden. Verder geeft een test aan dat bedrijfsspecifieke factoren, waaronder bedrijfsspecifieke drempels voor investeringen, aanwezig zijn. Deze bedrijfsspecifieke drempels kunnen echter niet worden berekend omdat ze niet gescheiden kunnen worden van andere bedrijfsspecifieke factoren.

Restricties op productie leiden niet alleen tot onderbenutting van kapitaalgoederen zoals aangegeven in hoofdstuk drie, maar ze leiden ook tot een vermindering van de investeringen op lange termijn. Gevolgen van lagere investeringen zijn onder andere dat innovaties minder snel worden geïntroduceerd en dat investeringen die bijdragen tot het oplossen van het milieuprobleem verminderen. In hoofdstuk vijf wordt getest of het systeem van mestproductierechten, dat in 1987 in Nederland is ingevoerd, van invloed is geweest op investeringen van Nederlandse varkensbedrijven. Gegeven de relatie tussen aantallen varkens en de productie van mest, impliceert invoering van een systeem van mestproductierechten ook een beperking van productie van varkens. Het is echter niet duidelijk of investeringen ook verminderden door deze impliciete productiebeperking. Het theoretisch model laat zien dat een productiebeperking leidt tot verminderde investeringen. Vervolgens is een test ontwikkeld om na te gaan of dit effect ook daadwerkelijk aanwezig is geweest. De test resultaten ondersteunen de hypothese dat het systeem van mestproductierechten heeft geleid tot verminderde investeringen op individuele varkensbedrijven na 1987. Lagere investeringen in deze periode kunnen de toekomstige concurrentiepositie van de sector hebben aangetast.

Hoofdstuk zes vat de belangrijkste conclusies samen en bespreekt twee belangrijke aspecten van dit proefschrift, namelijk de theorie van aanpassing van quasi-vaste productiemiddelen en het in acht nemen van heterogeniteit van boerenbedrijven. Dit hoofdstuk sluit af met enkele suggesties voor vervolgonderzoek.

CURRICULUM VITAE

Cornelis Gardebroek werd 7 februari 1973 geboren te Zwolle. Van 1985 tot 1991 doorliep hij het Voorbereidend Wetenschappelijk Onderwijs (VWO) op het Lambert Franckens College te Elburg. In 1991 begon hij aan de studie Agrarische Economie aan de toenmalige Landbouwuniversiteit Wageningen. In 1996 studeerde hij af in de richtingen Algemene Agrarische Economie en Staathuishoudkunde. Tijdens zijn studie verbleef hij gedurende 3 maanden aan de Pennsylvania State University.

In oktober 1996 begon hij als assistent in opleiding (aio) aan een promotieonderzoek bij de toenmalige vakgroep Algemene Agrarische Economie en Landbouwpolitiek van de Landbouwuniversiteit Wageningen. In 1999 behaalde hij het diploma van het landelijk Netwerk Algemene en Kwantitatieve Economie (NAKE).

Sinds mei 2001 is hij voor 2 dagen per week als universitair docent verbonden aan de leerstoelgroep Agrarische Economie en Plattelandsbeleid van Wageningen Universiteit, waar hij onderwijs geeft en onderzoek doet op het gebied van de empirische econometrie. Daarnaast werkt hij 3 dagen per week als postdoctoraal onderzoeker bij de Mansholt Graduate School van Wageningen Universiteit aan een onderzoeksproject getiteld ‘Omschakelen of niet: een empirisch micro-economische studie naar beslissingen van agrariërs omtrent het omschakelen naar duurzame productietechnieken’.