Investment decisions of french dairy farms: The case of Brittany

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Par
Loïc LEVI

INVESTMENT DECISIONS OF FRENCH DAIRY FARMS: THE CASE OF BRITTANY

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Abstract

Investment and innovation play an important role in the agricultural sector, allowing farms to adapt to policy changes and market condition changes. In the last decades, farms in the European Union (EU) have faced substantial changes in the Common Agricultural Policy (CAP). This is particularly the case of the dairy sector, which has seen the end of milk quota regime and an increased price volatility. Such changes could affect farm productivity and efficiency, the dairy sector's competitiveness and structural change. Understanding the mechanisms underlying farms' investment behaviour could allow identifying key drivers that influence the observed trends. This could help anticipate future structural changes, predict farms' needs and help policy makers and other stakeholders in farming to adapt their policy. The thesis contributes to this objective by analysing for dairy farms in a sub-region of Brittany (Ille-et-Vilaine) in France, (i) the impact of the termination of the milk quota on farmers' investment decisions and the heterogeneity of farm investment behaviour, (ii) the link between farm performance and farmers' investment decisions, (iii) the role of social interactions related to neighbourhood effects on farmers' investment decision.

Findings show that the ending of the dairy quota policy increased farmers' incentive to invest, contributing to the trend towards larger, more capital intensive and more specialised dairy farms. In addition, the thesis underlines the need to take into account farmers' heterogeneity in modelling investment behaviour. Doing so allows differentiated strategies to be revealed and can help design targeted policies aiming at encouraging investment, in particular in the context of quota system elimination. Finally, the thesis provides evidence that farmers account for their neighbours' decisions when they make large investment decisions. However, although neighbourhood effects are a positive multiplier in farms' investment decisions, policies should also take into account that farms face adjustment costs when implementing investment projects.

Keywords: farm investment, agricultural policy, quota, performance, adjustment cost model, spatial neighbourhood effects, social interaction, dairy sector, France.

Résumé

L'investissement et l'innovation jouent un rôle important dans le secteur agricole, permettant aux exploitations de s'adapter aux changements de politiques et aux conditions du marché. Au cours des dernières décennies, les exploitations agricoles de l'Union européenne (UE) ont été confrontées à des changements substantiels à travers la politique agricole commune (PAC). C'est notamment le cas du secteur laitier, qui a vu la fin du régime de quotas laitiers et également vu une volatilité accrue des prix. De tels changements pourraient affecter la productivité et l'efficacité des exploitations agricoles, la compétitivité du secteur laitier et les changements structurels. Comprendre les mécanismes sous-jacents au comportement d'investissement des exploitations pourrait permettre d'identifier les principaux facteurs qui influent sur les tendances observées. Cela pourrait aider à anticiper les futurs changements structurels, prévoir les besoins des exploitations et aider les décideurs publics et les autres acteurs du secteur agricole à adapter leurs politiques. La thèse contribue à cet objectif en analysant pour les exploitations laitières d'une sous-région de Bretagne (Ille-et-Vilaine) en France, (i) l'impact de la suppression du quota laitier sur les décisions d'investissement des agriculteurs et l'hétérogénéité de leurs réactions (ii) le lien entre la performance agricole et les décisions d'investissement des agriculteurs, (iii) le rôle des interactions sociales liées aux effets de voisinage sur la décision d'investissement des agriculteurs.

Les résultats montrent que la fin de la politique des quotas laitiers a incité les agriculteurs à investir, ce qui a favorisé les fermes laitières plus grandes, à plus forte intensité de capital et plus spécialisées. En outre, la thèse souligne la nécessité de prendre en compte l'hétérogénéité des agriculteurs dans la modélisation du comportement des investissements. Cela permet de révéler des stratégies différenciées et peut aider à concevoir des politiques ciblées visant à encourager les investissements, en particulier dans le contexte de l'élimination du système de quotas. Enfin, la thèse prouve que les agriculteurs prennent en compte les décisions de leurs voisins lorsqu'ils prennent de grandes décisions d'investissement. Cependant, bien que les effets de voisinage soient un facteur multiplicateur positif dans les décisions d'investissement des exploitations agricoles, les politiques devraient également prendre en compte le fait que les exploitations font face à des coûts d'ajustement lors de la mise en œuvre de projets d'investissement.

Mots clés: investissement des exploitations agricoles, politique agricole, quota, performance, modèle de coût d'ajustement, effet de voisinage, interaction sociale, secteur laitier, France.

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Glossary

AES: Agro-Environmental Schemes

CAP: Common Agricultural Policy

DEA: Data Envelopment Analysis

DPA: « Dotation Pour Aléas »

DPI: « Dotation Pour Investissement »

EU: European Union

HAC: Hierarchical Ascendant Classification

HCI: High Capital Intensity

LCI: Low Capital Intensity

LU: Livestock Unit

SFP: Single Farm Payment

SLX: Spatial Lag of X model

TORA: Theory Of Reasoned Action

TPB: Theory of Planned Behaviour

UAA: Utilised Agricultural Area

CHAPTER 1.

General introduction

1.1 Introduction

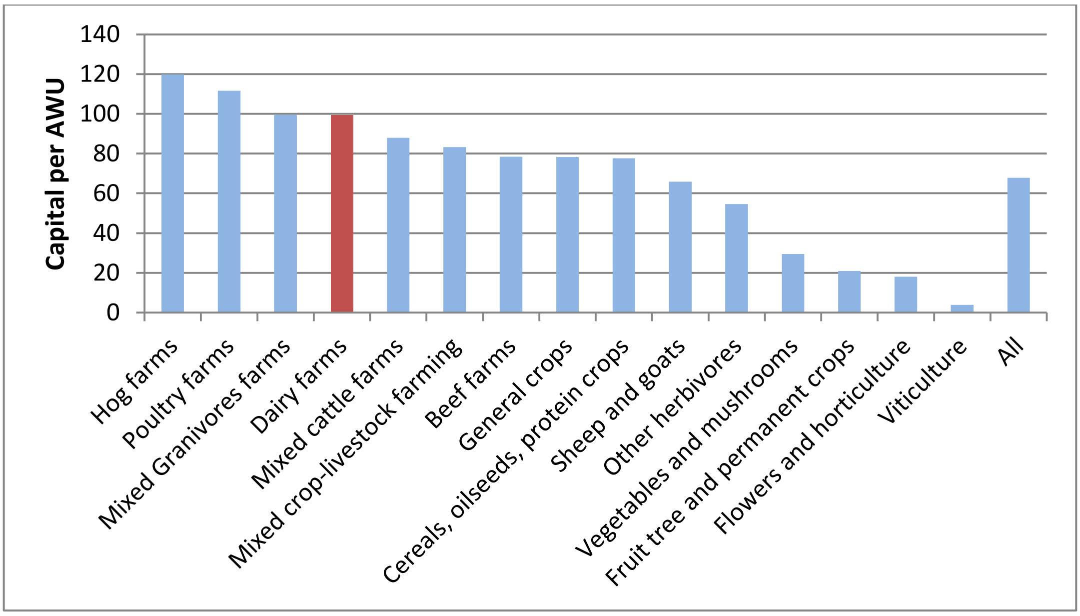
In the last century, investment and innovation played an important role in the agricultural sector, especially in Western Europe and the United States, allowing farms to adapt to policy changes and market condition changes and inducing structural changes. Since the end of the 20th century and especially after the 1950es, technological change, allowing the substitution of capital to labour, has been one of the most striking features of the agricultural activity transformations (Schultz, 1964). A comparison of agricultural production patterns in France between the last century (1955) and the beginning of the 21th century (2000) shows that, while the total agricultural production in 2000 was higher than in 1955, the total harvested cropland had declined, as well as the share of agricultural labour force in total population (from 31 to 4.8 percent) and the number of people employed in agriculture (from 6.2 million to 1.3 million). These statistics suggest that labour productivity has increased and agricultural technologies have significantly changed. This has been possible through agricultural sector structural change, which resulted in the enlargement of farms and huge technological change. Such changes in the structure of the farming sector have been possible thanks to important farm investments and have long been the subject of considerable interests among agricultural economists, policy makers and other stakeholders.

However, the investment issue has been approached by different points of view reflecting different needs (credit access, policy changes, market changes, etc.). The 'New Palgrave' Dictionary of Economics defines investment as "capital formation-the acquisition of creation of resources to be used in production. In capitalist economies much attention is focused on business investment in physical capital – buildings, equipment, and inventories" (Coen and Eisner, 1987). Commonly, firms invest to renew their assets, to increase their productivity, to increase their production capacity, to modernize the obsolete capital stock in order to become competitive, to change the long-term technical model and to adjust to an incentive (settlement aids, complying with standards, market price changes). Thereby, firm investment contributes to spread up technological progress and to increase productivity.

The agricultural sector is particularly affected by changes in market conditions and regulatory conditions, which encourage farms to adjust production and investment in capital assets. These changes relate, for instance, to the Common Agricultural Policy (CAP) in the European Union (EU) and its various reforms since its implementation in 1962. The dairy sector was particularly affected by the implementation of milk quotas in 1984 and also by the end of these quotas in 2015. Farms' investment is likely to affect input productivity and farm efficiency. In a macro-economic perspective, investment may enhance the dairy sector's competitiveness and its structural change, which could also affect other sectors of the economy because of farms' interconnections with the downstream sector (agri-food industry) and upstream sector (the providers of inputs and services). Understanding the mechanisms underlying farmers' investment behaviour could allow identifying key drivers that influence it. This could help to anticipate future structural changes, farms' needs and help policy makers and other farming stakeholders to adapt their strategy.

Investment decisions are particularly crucial in dairy farming, which is a highly capital-intensive business, requiring large initial investment in capital assets such as buildings, machinery and livestock. Figure 1.1 shows that dairy farms in France are highly capital intensive on average, ranked 4th among all farm main productions.

FIGURE 1.1: Average farm capital intensity, measured as capital per AWU, for main productions in 2016



Source: http://agreste.agriculture.gouv.fr/page-d-accueil/article/donnees-en-ligne

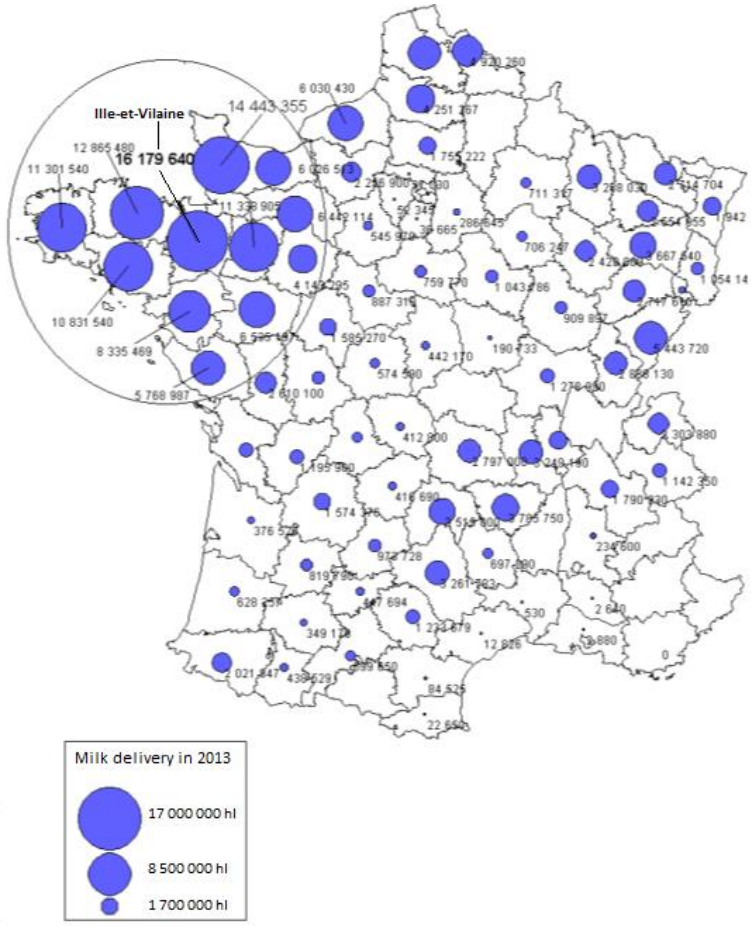
Note: AWU is agricultural working unit

The dairy sector has been affected by substantial changes in market conditions in the past recent years, namely the removal of the CAP milk quotas, which took place in 2015, and the milk price crisis that occurred in 2009. Implemented since 1984, the CAP milk quotas policy restricted the milk volume that each farm could produce (Boots et al., 1997; Guyomard et al., 1996). However, in 2008, the European Commission announced a removal of the CAP milk quotas effective in 2015. Moreover, in 2009, the dairy sector underwent a sudden decrease of milk price inducing a deep crisis. Both the removal of the CAP milk quotas and the milk price crisis might have strongly affected farms investment behaviour. For these reasons, the dairy farming sector is particularly interesting for an investigation of investment behaviour.

More precisely, we use the case study of commercial specialised dairy farms in Western France: namely the Ille-et-Vilaine sub-region (NUTS3)[1] between 2005 and 2014. This sub-region of Britany is an interesting case study because it is the first dairy NUTS3 sub-region of France, producing for example 5.4 billion of milk in 2014. Moreover, 50% of the Ille-et-Vilaine commercial farms are specialized in dairy production.

[1] The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU' (https://ec.europa.eu/eurostat/web/nuts/background).

FIGURE 1.2 : Case study of the Ille-et-Vilaine commercial milk farms



Source: Cartographie SETRIS / VEP – Avril 2014 – Direction Départementale des Territoires et de la Mer de la Manche

Note: hl is hectolitre (100 litres)

This chapter presents a global view of farmers' investment behaviour. Section 1.2 shows the weight of investment in the agricultural sector by recalling the most important changes in the agricultural sector and especially in the breeding livestock sector in Western Europe from the beginning of the 20's century to nowadays. Section 1.3 presents the common theoretical framework of firm investment behaviour and its assumptions. Section 1.4 presents the main objectives of the thesis and research questions. Section 1.5 points out the main contributions. Finally, section 1.6 explains the thesis' outline.

1.2 The trend of investment in the breeding livestock sector

As previously mentioned, investment played an important role in the agricultural sector in France, being a driving force of the structural changes since the 1950's. This section exposes the main changes in the agricultural sector and especially in the breeding livestock sector in Western Europe from the 1950's to nowadays, explaining how it was driven by investment.

- **From 1950 to 1970: After World War II**

After the end of World War II and the Marshall Plan implementation in 1947, European agriculture has undergone significant structural changes. After 1950, mechanization increased sharply with generalization of the tractor favoured the substitution of capital to labour. It allowed removing the working horses and working cattle. This allowed releasing agricultural area and stable places to put more cows. The availability of fertilizers and pesticides favoured the specialization of regions in field cropping depending on the quality of the soil and farm structures, and in livestock breeding in other regions. It has been one of the most striking features of the agricultural activity transformations at this period.

In 1960, French dairy farms were characterized by many small farms with an average of 6 cows per farm with mixed breeds. At this time, the priority for the EU was to ensure food security and protect the European market by using different instruments such as controlled price and trigger price mechanisms without limit of volume. In addition to that, the "breeding farm law" was adopted in 1960 and applied in 1970. The main aim of this law was to improve genetic selection of breeding livestock, develop means to improve performance monitoring and spread artificial insemination technology. A better genetic selection generated competition among breeds, doing quantity produce, the most important criterion, and contributed to milk specialization. Moreover, the animal science research has made huge progress, resulting in the "Frisonne Pie Noire" introduction, a new cow breed producing more milk[2]. All these changes had great impacts on the breeding system because the feed needs of the new breeds had changed, toward an increasing of the share of concentrated feed and maize silage, and a decreasing of grazing. Then, farms had to adapt by investing, in free stabling system for example, allowing to automatize animal feeding and milking, and facilitate the cleaning of buildings as well.

[2] The "Frisonne Pie Noire" will later be used as a strain to the Holstein

Another important shift in the breeding system was the great expansion of forage maize in many regions especially in plain regions, at the end of the 1960's. New types of machinery were adopted by farmers in order to adapt to this new farming system, such as forage harvester chopper, free stabling system and silo self-service allowing facilitating the feed distribution. Moreover, at this time, for sowing and harvesting, farmers started organizing themselves in cooperatives sharing agricultural machinery, which are now the privileged places for exchange and dissemination of innovations. This type of organization favours grass silage thanks to investments in more efficient equipment.

- **From 1970 to 1984: Before milk quota implementation**

During this period one of the main objectives of the CAP was to make the EU self-sufficient by producing more, pursuing a so-called "productivity orientation". This orientation encouraged farmers to produce more, supported by several measures such as guaranteed price, and subsidies coupled to production. Following this, from 1970 to 1983, French milk collection increased by almost 40% while the number of farmers was divided by two. During this period, there was an increase in production of more than 100 kg per cow per year, due to the improvement of both feed and genetic potential (Pflimlin et al., 2009). Farms became more and more modernized with the construction of cubicle stalls and milking parlours, and the mechanization of the distribution of forage and concentrates. Indeed, farms followed a trend toward intensive farming system. In the Western part of France, farms were simultaneously seeking fodder intensification by replacing grass area with a growing share of forage maize. Consequently, between 1970 and 1983, milk production doubled in Brittany (a NUTS2 region in Western France with main town Rennes, one of the NUTS3 sub-regions being Ille-et-Vilaine), increased by 75% in the neighbouring NUTS region of Pays-de-la-Loire (a NUTS2 region in Western France with main town Nantes) while it only increased by 20% in the rest of France (Pflimlin et al., 2009). This resulted in the growth and the concentration of milk production in these two Western regions and also in a significant increase in industrial production of butter and milk powder, two products largely supported by the CAP.

Both regions produced two-thirds of butter and skim milk powder in France. The weight of these two regions became particularly important in 1982-1983 (Guesdon, 1985). It was also the case for other EU regions, which experienced similar growth in output such as Ireland, Northern Germany and the Netherlands. In the same way, a large part of the production of these countries was processed into butter and powder. Between 1973 and 1983, EU milk production increased by 1.6% per year, while consumption of dairy products increased by only 0.5% per year. The gap between production growth and consumption growth meant that the EU price support program in place during this period became increasing costly for EU taxpayers in two ways: 1) increasing cost of public stocks for dairy products; and 2) increasing subsidies for dairy exports. The EU policy response to this situation was the establishment of a quota system for milk deliveries, introduced in 1984, to regulate the milk supply (Naylor, 1987). The EU quota policy restricted how much milk each farm could produce (Boots et al., 1997; Guyomard et al., 1996).

- **From 1984 to 2003: During quota implementation**

The quota implementation encouraged farms to produce less milk and encouraged the stabilization of the EU milk production. However, the way to manage quotas was different between countries. Indeed, quotas were allocated to each country, based on 1981-1983 milk deliveries, corrected by the milk deliveries growth. Therefore, countries with high dairy production growth and surpluses such as Denmark, the Netherlands and France, underwent between 10% and 15% reduction of their milk production, while countries with production deficit such as Italy, Greece and Spain, benefited from extensions based on their milk production of 1983 (Pflimlin et al., 2009). Likewise, countries for which the weight of the dairy sector was higher, such as Ireland, benefited from a preferential regime (Guesdon et al., 1995). Moreover, countries adopted different strategies to manage the quota. Countries with largest farm structures such as the Netherlands and the United Kingdom organized a freely tradeable quota market allowing an acceleration of dairy farms' restructuring. Indeed, under freely tradeable quotas, more efficient farms could buy quotas from less efficient farms. In France there was no quota market and it was prohibited to sale quota. In addition, France encouraged farmers' retirement or conversion by implementing a "milk cessation program" in 1995. This allowed freeing up quotas to allocate them, preferentially and freely, to young farmers. This program speeded up French' farms decreasing trend in the number of farmers and dairy cows. Between 1984 and 2009 in France, the number of farmers was divided by 5, and the number of dairy cows was divided by 2, while milk production per dairy cow increased by 1.6 (Pflimlin et al., 2009). Thus, during this period, most of French dairy farms increased cow and forage intensification in order to produce up to the quota with a minimum number of cows and diversified into other crops such as cereals, young meat cattle, or suckler cows. This diversification secured income, but also resulted in additional costs of mechanization and additional work. In some less favoured areas, farms chose to increase their product added value by producing under registered designation of origin ("Appellation d'Origine Contrôlée", AOC), organic practices, or selling through direct sales (Pflimlin et al., 2009).

- **From 2003 to 2015: The end of dairy quota**

Under pressure from the World Trade Organization, proposals were made in 2003 to reform the EU agricultural policy with a progressive reduction in market regulations leading to the eventual elimination of EU milk quotas in 2015. As world demand for dairy products expanded during the last two decades, the quota system prevented EU producers from expanding milk production to help meet the growing world demand.

The end of the EU dairy quotas was confirmed in 2008 with a range of measures aimed at achieving a "soft landing" policy, where milk quotas were gradually increased, leading up to their abolition on March 31, 2015. The European quota increased by 2% in 2008/2009 and then 1% per year until 2015. Since the 2008 announcement of milk quota abolition, French farmers adapted to changing market and policy conditions, resulting in an increase in milk production toward the end of milk quotas. In Brittany milk deliveries increased by 15.9% between 2009 and 2015 (DRAAF, 2017), and 70% of dairy farms expanded, with +26% of milk deliveries per farm between 2008 and 2014 (Chambre agriculture, 2015). This important shift reflects changing investment incentives on dairy farms associated with the ending of EU quota policy.

- **The role of public policy in farm investment**

The role of public policy in farm modernisation has long been discussed in the literature (Karanikolas and Martinos, 2007; Lobley and Butler, 2010). In the last centuries, farm modernisation was also driven by the CAP through the Common Organization of agricultural Markets (COM) and through the first and the second pillar subsidies. In fact, in 1962 the COM, which manages the market, product marketing standards and EU exports and imports, was implemented. This is the COM that established market interventions such as storage aids or export subsidies. Also, the dairy quota was implemented in 1984 through the COM. Then, in 1992 the Mac Sharry reform introduces direct income support to compensate for market intervention declines. The main objective of this direct subsidy is to give farmers a guaranteed minimum income. In 2003, after the CAP mid-term review (Luxembourg Agreement), this direct income support was provided through the decoupled Single Farm Payment (SFP). Also, in 2000 and the Cork conference, the two pillars of the CAP were established. The first pillar of the CAP takes the form of a farm income support, while the second pillar is a rural development policy aiming to maintain the socio-economic dynamism of rural areas. In the first pillar, there are direct subsidies to farmers, which are the main instrument of the CAP (about 70% of the budget according to the European Commission).

There are three types of payments to farmers in the first pillar: 1) the SFP, so called "basic payment", is a harmonized aid per hectare at national or regional level and is the bigger support part of this pillar; 2) a green payment is a subsidy received by farmers if they comply with three conditions (have two or three different crops on the farm, maintain permanent grasslands and areas of ecological interest); 3) a redistributive payment (for example, member states can choose to allocate part of the aids for small farms instead of larger farms). In the second pillar, there is a wide range of objectives (also co-financed by the member states), such as farm modernization, farmers' training, new farm settlements, conversion to organic farming, etc.

Also, several bodies or institutes having for main goals to accompany and advice farmers in their accounting or farming system management have been created or used. These institutes are acting as part of the CAP. For example, during the oil crisis happened over the period 1930-1945, it was difficult to obtain financing from the bank because of a rise of the interest rates. However, the introduction of subsidised loans in the agricultural sector between 1965 and 1980 allowed reducing the financial burden for farmers. Subsidised loans have lower rates than those in the market because the EU paid a portion of the interest in the form of a subsidy. So, the financing of farm investments has been ensured by banks through subsidised loans. Another example of the role of public policy in agriculture mechanisation is the creation, in 1924, by the French government, of the chamber of agriculture having for objective to represent all the different economic agents of agriculture and also to apply agricultural and rural development policies in France. The role of public policy in farm modernisation has long been discussed in the literature (Karanikolas and Martinos, 2007; Lobley and Butler, 2010).

- **The role of adoption of innovation**

During the last century, many innovations have been adopted by farms, accompanying the structural and technological change. Above, we mentioned the adoption of tractor allowing the substitution between capital and labour, artificial insemination, breeding selection, free stabling system, self-service silo, new type of organization such as cooperatives sharing agricultural equipment, milking machine, milking robot and new agricultural practices (organic milk, labels stating the origin, etc.). These innovations allow farmers adapting to changes. In our case study, the main change in the agricultural policy is the end of the dairy quotas, and this may have modified farmers' decisions and hence capital structure through investment incentives. To adapt, farmers may have expanded, specialized or diversified their production, and in some cases adopted innovations, in terms of production technology or farm organization. However, farmers' ability to adapt, innovate and invest differs, depending on economic factors, demographic factors, locational factors, or on their inclusion in social networks. Also, this is why all these above mentioned innovations have not been instantaneously adopted and took some time before spreading among farmers, for several reasons: low opportunity cost, low degree of education, low social interaction with neighbours or with social network organization. For example, Manuelli and Seshadri (2014) show that, for the case study of tractor, the reason for the slow rate of diffusion was that "*tractor quality kept improving over time and, more importantly, that only when wages increased did it become relatively unprofitable to operate the alternative, labour-intensive, horse technology*". In the case of the adoption of organic drystock farming in Ireland, Läpple and Kelley (2015) raise the importance of farmer interactions in adoption decisions and reveal that farmers located in close proximity exhibit similar choice behaviour. Likewise, Läpple et al. (2017) show that spatial effects spill over to neighbours and better educated farmers are more likely to adopt sustainable technologies in the Irish dairy sector. In the case of new maize variety adoption in Mozambique, Fang and Richards (2018) argue that farmers in developing countries can increase their productivity by adopting new plant varieties, but informational barriers can slow down or stop the adoption. Some innovations may be a turning point in the sector, allowing productivity gains leading to greater competitiveness or even higher well-being on the farm. In a new institutional and market environment given by the end of quotas, it is necessary to identify the potential innovations that will allow face this change, but also to understand the mechanisms, especially the role of social interactions, underlying farms investment decisions.

1.3 Modelling firm investment behaviour in economics

Modelling firm investment behaviour, supposes to make some assumptions about why firms invest. In the previous sections, we did evoke some factors that influence farm investment behaviour such as public policy (milk quota), the evolving trend of the market price, the access to credit, etc. However, introducing all these factors in a modelling strategy is difficult to do, and has long been discussed in the literature. The purpose of this section is to provide a short review of diverse investment theories and to find the most suitable theoretical framework accounting for the assumptions about firm's investment decisions. First, we start with the rigid accelerator theory elaborated by Clark (1917), which stated that investment is only proportional to changes in output, following equation (1.1):

$$I_t = a(Y_t - Y_{t-1}) \tag{1.1}$$

Where I_t is firm investment, a is a constant and Y_t is the level of output in time *t*. This approach has been criticized by number of economists such as (Kuznets, 1935; Tinbergen, 1938; Tinbergen, 1938; Chenery, 1952; Koyck, 1954; and Hickman, 1957), because it suffers from several limits. Firstly, this model considers only demand or changes in demand as determinant of investment behaviour. Moreover, output is not considered as a good proxy of demand. Secondly, this theory assumes that capital is optimally adjusted in each period, meaning that firms are always in equilibrium. Finally, it is a comparative static analysis while investment is a dynamic phenomenon.

Chenery (1952) and Koyck (1954) proposed a more elaborated approach called the flexible accelerator theory. It overcomes one of the major shortcomings of the rigid accelerator model, by relaxing the assumption that capital is optimally adjusted in each period. So, capital is adjusted at the desired level accounting for a possible error, which is the difference between the desired level and the actual level in each period following equation (1.2):

$$\mathrm{K_t} - \mathrm{K_{t-1}} = (1 - a)(\mathrm{K_t^*} - \mathrm{K_{t-1}^*}) \tag{1.2}$$

Where K_t is the current level of capital in period, K_t^* desired level of capital in period *t*. Then, the replacement of capital has been theorized by assuming that replacement of capital is proportional to actual capital stock, following equation (1.3):

$$K_t - K_{t-1} = I_t - \delta K_{t-1} \quad (1.3)$$

Where δ is the depreciation rate of capital. Combining equations (1.2) and (1.3), we obtain the following equation (1.4):

$$I_t - \delta K_{t-1} = (1 - a)(K_t^* - K_{t-1}^*) \quad (1.4)$$

Despite the ability of the flexible accelerator model to relax the assumption that capital is optimally adjusted in each period, it suffers from additional shortcomings. Firstly, it does not take explicitly into account the output prices, interest rate, input price, etc. Secondly, it does not allow discussing about investment incentives from a policy point of view.

Then, thanks to the works of Roos and Von Szeliski (1943), the neoclassical theory of investment was considered as a good alternative to the previous theory. The principle is that each farm and at each period determines an optimal path for capital accumulation. So the desired level of capital is derived from a maximisation program of the present value of the future expected net revenue, over an infinite horizon. One of the main advantages of this theory is that it allows accounting for interest rate. However, this theory assumes that the desired level of capital is a function of relative prices and not output. Moreover, the way in which the cost of capital and the prices of investment goods enter the demand for capital has not been studied from a theoretical point of view, at this time.

Jorgenson and Stephenson (1967) works overcome this shortcoming by revisiting the neoclassical theory of optimal capital accumulation. The difference with the last neoclassical theory is the definition of cost of capital and the definition of the present value. The cost of capital includes interest rate component reflecting the interest cost of investment, a depreciation rate of capital component, measuring the depreciation cost and a term capturing speculation related to investment price changes. The present value of the firm is defined as the sum of discounted profit (revenue minus outlays and taxes) over a τ-period planning horizon. This model relies on a production function transcribing flows of output, labour, capital and services, to characterize the productive process. From this, the present value is maximized subject to a constraint on replacement of capital which is proportional to actual capital stock following equation (1.3). Jorgenson and Siebert (1968) showed that the performance of the neoclassical theory of investment was better than the other alternatives and showed the important role of inflation, in explaining investment. However, this model is stated under assumptions that the capital market is perfect meaning that each individual or firm has access to loans and has the same expectations about the future on interest rate. Depending to the case study, this assumption could be false.

Moreover, this model makes the assumption that the world market is perfectly certain about the future which is not necessarily true. Indeed, previously, in standard investment models, credit market is supposed to be perfect. Under this assumption, Modigliani and Miller (1958) stated that internal and external financing are perfect substitutes and there are no credit constraints and limitations, and assume that all companies undergo the same financial constraints (so, there is no information asymmetry). Therefore, in a perfect credit market, financial constraints play no role on investment decisions, but in reality credit markets might be affected by imperfections. Fazzari et al. (1988) propose a test of financial constraints hypothesis. Then, they suggest introducing a cash flow variable into standard investment models. This method is based on the idea that, if firms do not face financial constraints, their internal financing (profits) and their external financing (credit) have the same cost in equilibrium and thus are perfect substitutes; in this case, no financial variable should play a role in the investment decisions. By contrast, financial constraints mean that there is a gap between the cost of internal financing and the cost of external financing, and either one or the other financing means would be a determinant of investment. Thus, introducing a cash flow variable (a variable proxying the firms' availability of internal financial resources) provides the possibility of testing for the presence of financing constraints. The role of access to credit has long been tested and discussed in the literature, the lack of access being a brake to modernization and to capitalization in agriculture. This has been the case of many European countries in the 1960's and also of Eastern European countries in the 2000's. Indeed, numbers of articles show that the agricultural market of investment is not perfect because of the limited access to credit for certain farms, so the capacity to invest is limited in some countries (Latruffe, 2005). However, in our case study of Ille-et-Vilaine (a sub-region of Britany in western part of France) between 2005 and 2014, we consider that there is no limited access to credit. Indeed, according to field experts from the bank "Credit Agricole", the access to credit is not limited.

Additionally, this model assumes that each firm is able to adjust capital costlessly and instantaneously meaning that there is no consideration about future expectations. This also means that each firm adjusts instantaneously the capital after an increase in the price of capital. This assumption is unrealistic given the nature of capital in particular in the agricultural sector (due to the fixity of assets). There are adjustment costs referring to i) the ongoing frictionless flow (maintenance); ii) the gradual adjustments (refinements and training dependent improvements); iii) the major and infrequent adjustments. So, incentives to invest may be muted by the presence of adjustment costs. Therefore, relaxing this assumption was the extension of research about firm investment behaviour. Then, literature commonly assumes that adjustment costs are a function of rate of investment and capital, increasing with rate of investment/disinvestment. The adjustment cost function is assumed to be strictly convex meaning that investment will follow a smooth pattern. In other words, adjustment costs give incentive to smooth investment over time.

Until now, even if theoretical frameworks have been improved along time, it still needs more work. Firstly, firm heterogeneity needs to be accounted for, as shown in chapters 2 and 3. Secondly, some improvements are needed about the production function (commonly, it is the Cobb-Douglas function which is used). In fact, using a non-parametric estimate of the production function, instead of a parametric one such as Cobb-Douglas function, has several attractive characteristics: i) it provides a flexible representation of the multi-output production technology; ii) it avoids endogeneity issues (since it does not involve estimating any parameters). To do so, chapter 2 proposes a non-parametric estimate of the production function. Thirdly, adjustment costs, which are already accounted for in previous studies, need to be distinguished between adjustment costs due to capital increase and adjustment costs due to capital decrease. Indeed, Lansink and Stefanou (1997) have shown that adjustment costs are asymmetric (adjustment costs are higher for a capital decreasing than a capital increasing). Chapter 2 proposes a new approach allowing distinguishing both types of adjustment costs in the theoretical model.

Fourthly, chapter 3 shows that performance in managing the farm system plays a role in farm future investment behaviour capturing the effect of adjustment costs. So, this demonstrates that farm performance needs to be accounted for in the theoretical model. Chapter 5 proposes a first attempt of a theoretical framework including performance explicitly, which could serve as a support for further developments.

Finally, all these theoretical models ignore the role of social interactions on firm investment behaviour. However, studies from the literature about technology adoption show that social interactions matter. Case (1992) suggests that after a technology adoption, farmers develop a degree of “positive or negative affect” towards the new technology which they then spread to their neighbours. So the network or the farm location can play a role in farmer investment behaviour. Chapter 4 proposes a novel way of empirically modelling the neighbourhood effects.

1.4 Objectives and research questions

The end of the EU dairy quota policy was confirmed in 2008 with milk quotas gradually increasing up to their abolition on March 31th, 2015. This change in the agricultural policy may trigger farmers' substantial investment decisions in order to increase their production capacity through expansion or modernisation. From a policy perspective, understanding the determinants of farm investment in a changing policy and economic context can help draw policy recommendations on how best to accompany farmers throughout the changes. In this context, this thesis will contribute to the understanding of the mechanisms underlying dairy farm investment decisions with a focus on Ille-et-Vilaine, a Brittany sub-region. The objective is threefold. Firstly, the thesis aims at investigating some determinants of these decisions, with a focus on the effect of quota removal. Secondly, we will study the role of farm past performance on farm future investment decisions. Thirdly, we will study the role of social interactions related to neighbourhood effect on farmers' investment decision.

1.4.1 Question 1: Does the removal of dairy quota create incentive to invest? Is this effect homogeneous across farms? If not, how does the effect vary for different farm types?

As explained in section 1.3, the economic literature has largely studied the determinants of firms' investment behaviour. The main determinants studied are economic including the output price, the capital price and the output quantity sold and, by extension, the output quantity produced (Chirinko, 1993). Later, financial determinants of investment have been studied in relation to financial constraints and interest rates (de Jong et al., 2000; Latruffe, 2005; O'Toole et al., 2014). Then, another more recent focus is the influence of public policy on investment (Bojnec and Latruffe, 2011; Sckokai and Moro, 2009; Serra et al., 2009) and the impact of quasi-fixity of assets, irreversibility of investment, sunk costs and adjustment costs (Bokusheva et al., 2009; Chavas, 1994; Lansink and Stefanou, 1997). A sharp policy change such as the recent quota removal has however not been largely studied in the investment literature. Chapter 2 contributes to this literature by studying the influence of the removal of dairy quota on investment incentives and studies whether this influence differs across farms. We study this question because the removal of dairy quota will probably have consequences on future farm structural change. So, understanding the heterogeneity of farms investment behaviour allows foresee what kind of farms and structural changes will arise in the dairy sector.

1.4.2 Question 2: Does farms' performance influence their future investments, considering that farms are subject to adjustment costs? Is the effect homogenous across all farms?

The literature on investment usually excludes one of the organisational factors that is managerial performance. In fact, investment generally implies a reorganisation of the farm management. This may involve substantive changes in equipment, facilities, types of inputs, and basic managerial strategy. Such changes may increase the level of sunk costs involved and the uncertainty regarding future performance. The effect of farm performance on investment is ambiguous. On the one hand, high farm performance (for instance better productivity inducing better income) can allow farmers to afford investment in the future, in line with the accelerator effect; on the other hand, farmers with a highly performing farm may postpone investment in order to avoid adjustment costs that would decrease their performance in the short term. However, the explicit investigation of the effect of current performance on future investment decisions has never been performed. This investigation is the core of chapter 3 in the thesis. The objective of this chapter is to investigate the role of farm performance on farm investment decisions. An adjustment cost model is used and performance is introduced in the modelling strategy, accounting for farm heterogeneity through different farm capital intensities. We consider two types of farms: one with high capital intensity and one with low capital intensity. Investment behaviour of both types of farms may differ for several reasons. Both types of farms may differ in their objective (capital accumulation vs. maintenance of profitability); they may differ in their current performance, which would differently affect future investment decisions; the adjustment costs may have a different impact depending on the initial capital endowment. Also, studying the influence of performance on farm investment behaviour, while differentiating farms in terms of their capital intensity, allows knowing more about future structural changes. This is crucial given the particular context of the end of the dairy quotas.

1.4.3 Question 3: What is the role of social interactions, in particular neighbourhood effects, in farm investment behaviour?

In this changing context, farmers need to identify potential solutions by learning new ways to manage information in order to reduce uncertainty. To do this, farmers need time and experience, they need to develop training strategies and to integrate various types of information in their management, including information shared with other farmers. Thereby, farmers differ in their ability to invest in order to adapt to their new environment for a number of reasons, such as economic constraints, demographic factors, locational advantages, or social interactions. These reasons introduce temporal and spatial variations in the investment decisions. Most of the literature on investment behaviour usually excludes neighbourhood effects, where neighbours have either a direct or indirect effect on individual behaviours (Wilson, 1987). One reason may be that it is usually believed that investment decisions, which are in fact input demands in a medium- or long-term horizon, are governed by managers' profit maximising behaviour and are thus only influenced by economic determinants. However, investment may be carried out to implement a new technology, whose literature in agriculture has recently recognised the importance of neighbourhood effects. Relying on the economic literature on the adoption of innovation, the objective of chapter 4 is to examine the spatial determinants of farmers' investment in particular the role of neighbourhood effects.

1.5 Main contributions

This thesis provides three mains empirical contributions to the existing agricultural economics literature.

Chapter 2 sheds new lights on the linkages between investment incentives and dynamic adjustments to market and policy changes. It also documents the heterogeneity of farmers' response to policy reform both over time and across farms and structural changes. To our knowledge, this is the first study that evaluates the influence of quota removal on the incentive to invest, in the presence of adjustment costs. Our novel and main contribution shows that farmers' incentives to invest have increased since the announcement of EU dairy quota removal, and that this policy reform has induced structural changes in the farm dairy sector by contributing to the trend toward larger, more capital intensive and more specialized dairy farms. From a policy viewpoint, our investigation suggests that policy reform affects the evolving structure of agriculture.

In chapter 3 we investigated investment behaviour accounting for the presence of adjustment costs and the role of farm performance. One performance indicator, which often appears in the literature since it directly derives from the theoretical model, captures the productivity of capital (i.e. output to capital ratio). We included other performance indicators, proxying managerial performance. Distinguishing these two types of performance is an important contribution because it allows capturing tax incentives to invest (through the productivity of capital) and disincentives to invest due to adjustment costs (through managerial performance). Also, we account for heterogeneity through different farm capital intensities. Indeed, we consider two groups of farms differing in terms of capital intensity: farms that have a high capital intensity, and farms that have a low capital intensity.

The results show that smoothing farm investment over time is an optimal strategy in the presence of adjustment costs. However, the influence of performance on farm investment differs between high capital intensity farms and low capital intensity farms, revealing a standardisation trend in terms of technology toward high capital intensity farms. Our findings highlight that farmers' heterogeneity needs to be accounted for in modelling investment behaviour. It allows differentiated strategies to be revealed and can help design targeted policies aimed at encouraging investment, in particular in the context of quota system elimination.

The main contribution of chapter 4 is to provide a better understanding of how farmers make their investment choice according to their neighbourhood. We account for the effect of past decisions made by farmer's neighbours, by using a spatial lag of X probit model (SLX), which is easier to implement than a dynamic spatial model. The methodological contribution is adding the variable "investment age" as an explanatory variable. This variable measures the time elapsed since the occurrence of the last investment spike. It also shows the influence of farms characteristics on the investment behaviour of their neighbour. We find evidence that farmers are not influenced by the current decisions of their neighbours, but rather by the previously-made decisions of their neighbours. The results reveal the role of neighbourhood effects in the occurrence of investment spikes and confirm that farmers account for their neighbours' decisions when they make important investment projects, such as for enlargement or for technology adoption. Also, the results reveal that farmers with high milk specialisation, high livestock density and smaller farm are more likely to make an investment spike.

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1.6 Outline of the thesis

The thesis is organized into five chapters including this general introduction. As explained above, the thesis is made up three research articles which have been written during the three years of the PhD course. Chapter 2 discusses the first research question. It examines the effects of agricultural policy on farm investment, with a focus on the removal of EU dairy quota. Chapter 3 addresses the second research question: it investigates the role of farm performance in investment decisions by estimating an adjustment cost model with performance indicators. Chapter 4 investigates the third research question, namely the spatial determinants of farmers' investment, in particular the role of neighbourhood effects. Finally, chapter 5 discusses and concludes. It summarises the main findings of the thesis, discusses them, provides some methodological and policy recommendations, exposes the limits of the analyses and provides some suggestions for further research.

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CHAPTER 2.

How Does Eliminating Quotas Affect Firm Investment? Evidence from Dairy Farms[3]

Abstract

In this chapter, we examine the effects of agricultural policy on farm investment, with a focus on the termination of European Union (EU) dairy quotas. Using a Jorgenson model, we examine the determinants of capital accumulation under adjustment costs. We apply this model to panel data on a sample of French farms and evaluate how the shadow price of milk quotas evolved during the period preceding the elimination of EU dairy quotas. The analysis documents how the "soft landing" policy change increased the incentive to invest and how this effect is heterogeneous across farms and time.

2.1 Introduction

Milk is an important agricultural product of the European Union (EU) and represents 15% of the value of EU agricultural production. The EU is a leading exporter of many dairy products, including cheese. Milk production is also very important in the agricultural economy of certain member states, such as Germany, France, Ireland, the United Kingdom (UK), the Netherlands, Italy and Poland, which together account for 70% of EU production. Thirty years ago, milk accounted for 19% of final agricultural production in the European Community. In 1983, France, Germany, the UK and the Netherlands accounted for 24.7%, 24%, 14.5% and 11% of European milk production, respectively. However, between 1973 and 1983, European milk production increased by 1.6% per year, while the consumption of dairy

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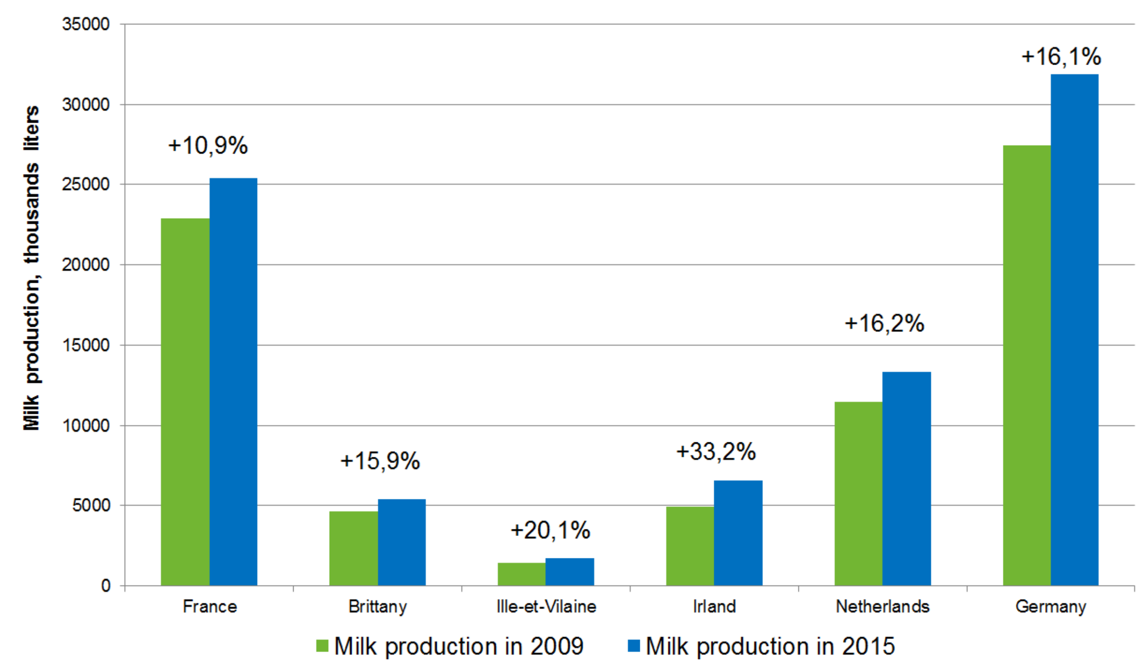
[3]This chapter is an article written with Jean-Paul Chavas (Department of Agricultural and Applied Economics, University of Wisconsin, Madison, USA).

products increased by only 0.5% per year. The gap between production growth and consumption growth meant that the EU price support program in place during this period became increasing costly for EU taxpayers in two ways: 1) the increasing cost of public stocks for dairy products; and 2) increasing subsidies for dairy exports. The EU policy response was the establishment of a quota system for milk deliveries introduced in 1984 to regulate milk production (Naylor, 1987). The EU quota policy restricted how much milk each farm could produce (Boots et al., 1997; Guyomard et al., 1996).

Under pressure from the World Trade Organization, proposals were made in 2003 to reform EU agricultural policy with a plan for a progressive reduction in market regulations leading to the eventual elimination of EU milk quotas in 2015. As world demand for dairy products expanded during the last two decades, the quota system prevented EU producers from expanding milk production to help meet growing world demand.

The end of the EU dairy quotas was confirmed in 2008 with a range of measures aimed at achieving a "soft landing" policy where milk quotas were gradually increased, leading up to their abolition on March 31, 2015. The European quota increased by 2% in 2008/2009 and then 1% per year until 2015. Agricultural policy influences farm capital structure and investment incentives. After the 2008 announcement of the milk quota abolition, French farmers had seven years to adjust and adapt to changing market and policy conditions. There was an increase in milk production in France toward the end of the milk quotas (see Figure 2.1). In Brittany, a major milk producing region in France, milk deliveries increased by 15.9% between 2009 and 2015 (DRAFF, 2017). This important shift reflects changing investment incentives on dairy farms associated with the ending of the EU quota policy.

FIGURE 2.1: Evolution of milk deliveries between 2009 and 2015 in main European dairy countries, in Brittany and in the Ille-et-Vilaine sub-region.



Source: Monthly dairy survey SSP-FranceAgriMer and Eurostat

The impact of the EU quota implementation and elimination has been studied in previous research. Regarding the UK case, Colman (2000) pointed out that dairy quotas generated inefficiency due to production constraints and led to the inability of milk producers to adjust to market conditions. He argued that dairy quotas increase costs for farmers wanting to expand milk production (approximately 12.5% of total milk revenues). Moreover, this scholar found that a large number of farms had difficulties meeting their quota constraints, indicating that a lack of fully tradeable quotas increased economic inefficiency. These arguments indicate that the abolition of the EU quota would entail subtantial benefits for the UK milk producing sector and create incentives to invest. Bouamra-Mechemache et al. (2002) argued that the removal of the EU milk production quotas is welfare improving both at the EU level and world level but only if substantial market and trade liberalization policies are enacted. For the case of Belgium, Ang and Oude Lansink (2014) argued that milk quotas prevented efficient production, as they supported high-cost producers, but they also improved efficiency better than the price supports under tradeable quotas. Indeed, under freely tradeable quotas, more efficient farms can buy quotas from less efficient farms to reduce the aggregate cost of meeting the EU quota, which is the reason milk quota transfers were allowed in the

EU after 1987, although the rules differed across EU Member States. Additionally, Ang and Oude Lansink (2014) estimated that the average inefficient underuse of variable inputs was approximately 60% in Belgium. Such results indicated that abolishing the milk quota system in 2015 would have a significant effect on the Belgian dairy sector, including an increase in farm input demands and in output supply.

The impact of EU dairy policy reform can vary across countries and regions. Indeed, the comparative advantage in milk production varies across agro-climatic zones (Bojnec and Fertő, 2014). For example, regions better suited to grow grass have some comparative advantage in producing milk. Heterogeneity in investment behavior could also appear in countries because the rules for milk quota transfers are different across member states. The incentive to invest would vary depending on whether freely tradeable quotas were allowed. In France, the quota market is thin and strictly regulated, and the regulations also vary across French regions. Finally, EU policy reform could have a differentiated effect on intensive dairy farms and extensive dairy farms, specialized dairy farms and diversified dairy farms or large dairy farms and small dairy farms. Such effects depend on the nature of economies of scale and economies of scope on dairy farms (Colman et al. 2002). Oskam and Speijers (1992) showed that larger and/or more efficient farms tend to increase their share of milk production. Ang and Oude Lansink (2014) found that, on average, underproduction and the underuse of variable inputs are much more pronounced on small and medium farms than on large farms. As a result, for small farms, removing the milk quota system may result in a drastic expansion of input use and output supply.

The impact of the EU quota implementation on investment behavior has been investigated by Ang and Oude Lansink (2014); Burton (1985) and Rasmussen and Nielsen (1985). However, the economic effects of the “soft landing policy” associated with the progressive elimination of the EU quotas remain poorly understood, which reveals the need to better understand the impacts of this policy reform on farmers' production adjustments and investment behavior. Some key questions are as follows: Does the “soft landing” policy create an incentive to invest? Is this effect homogeneous across farms? If not, how does the effect vary across farm types? The objective of this chapter is to answer these questions. This analysis investigates investment behavior based on a sample of French dairy farms.

Our analysis of farmers’ investment behavior starts with the neoclassical theory of optimal capital accumulation (Hall and Jorgenson, 1967). We formulate a dynamic optimization problem for a farmer making production and investment decisions. Optimal capital then corresponds to the situation where the expected marginal value of capital is equal to the user cost of capital. Our investigation allows for the presence of adjustment costs and examines the evolving role of quotas in farm investment incentives. This analysis is applied to panel data of 616 farmers in Britany (in Western France) over the period 2005-2014. To our knowledge, this is the first study that evaluates the influence of the quota removal on the shadow price of the quotas in the presence of adjustment costs. Our panel data analysis also allows us to document heterogeneity in dynamic adjustments made over time and across farms. Our novel and main contribution is showing that farmers' incentives to invest have increased since the announcement of the removal of the EU dairy quotas and that this policy reform has induced structural changes in the farm dairy sector by favoring dairy farms that are more specialized, use more intensive production systems and have higher capital intensity.

This chapter is structured as follows: section two develops the theoretical framework; section three presents the empirical application; and section four presents the results, while section five concludes.

2.2 Theoretical framework: the optimal investment path

In this section, we develop a theoretical framework based on the neoclassical theory of optimal capital accumulation (Hall and Jorgenson, 1967). We introduce a quota limitation as a constraint on milk output. We investigate farmers' investment decisions in the presence of adjustment costs. The inclusion of the constraint and adjustment costs provides a consistent theoretical basis for investigating agricultural investment patterns in the context of dynamically optimizing economic agents. Adjustment cost theory has been the main approach used in the literature on investment to explain why firms' adjustments in their capital stock is often slow (Bond and Meghir, 1994; Hubbard and Kashyap, 1992; Lizal and Svejnar, 2002; Rizov, 2004). According to this theory, firms have difficulties modifying their stocks of quasi-fixed production factors under changing market/policy conditions (Caballero, 1999). Such adjustment costs are relevant in the agricultural sector in the presence of asset fixity, especially in the livestock sector (e.g., as argued by Galbraith and Black, 1938). In a profit maximizing framework, the adjustment cost hypothesis is formalized by explicitly including lagged capital in the production function to capture the resources used in the process of adjusting capital stocks.

A farm typically produces several outputs using numerous production inputs. Joint production processes are used to generate outputs and require the use of a multi-output production function. As milk is only one of the outputs, this is a scenario where milk production quotas would affect only one of the outputs.

Consider a production process producing s outputs using m inputs. Let $\boldsymbol{y}$ be the output vector $\boldsymbol{y} = (y_1, \dots, y_s) \in \mathbb{R}^s$ and $\boldsymbol{x}$ be the input vector $\boldsymbol{x} = (x_1, \dots, x_m) \in \mathbb{R}^m$. Using the netput notation (where outputs are positive and inputs are treated as negative), the production possibility set at time t is

$$T(t) = \{(\boldsymbol{y}, -\boldsymbol{x}) \in \mathbb{R}^{s+m} : \boldsymbol{x}\ can\ produce\ \boldsymbol{y}\ at\ time\ t\} \quad (2.1)$$

where $T(t)$ is a non-empty, closed, convex and negative monotonic set (Färe and Grosskopf, 1985). At time t, consider observing a sample of n farms facing technology $T(t)$, where the i-th farm produces outputs $\boldsymbol{y}_{it}$ using inputs $\boldsymbol{x}_{it}$; $i \in N = \{1, \dots, n\}$.

The production function for the agricultural outputs (including milk) can be evaluated using a non-parametric approach called data envelopment analysis (DEA) (Banker et al., 1984; Charnes et al., 1978). A non-parametric DEA estimate of the production function has several attractive characteristics: 1) it provides a flexible representation of the multi-output production technology; 2) it does not require each farm to be on the production frontier; and 3) it avoids endogeneity issues (since it does not involve estimating any parameters). Using DEA, the technology at time t can be represented by the set:

$$T^e(t) = \{(\boldsymbol{y}, -\boldsymbol{x}) : \textstyle\sum_{i=1}^{n} \mu_{it} \boldsymbol{y}_{it} \geq \boldsymbol{y}, \sum_{i=1}^{n} \mu_{it} \boldsymbol{x}_{it} \leq \boldsymbol{x}, \sum_{i=1}^{n} \mu_{it} = 1,\ \mu_{it} \in \mathbb{R}_+, i \in N\} \quad (2.2)$$

The set $T^e(t)$ in (2.2) is the smallest convex set that satisfies free disposal and includes all data points in the sample of n farms at time t. The constraint $[\sum_{i=1}^{n} \mu_{it} = 1]$ in (2.2) corresponds to a DEA representation of $T(t)$ under variable returns to scale (Banker, Charnes and Cooper, 1984). Note that equation (2.2) without the constraint $[\sum_{i=1}^{n} \mu_{it} = 1]$ would give a DEA representation of $T(t)$ under constant returns to scale (Charnes, Cooper and Rhodes, 1978). Our analysis is based on equation (2.2) because imposing constant returns to scale can lead to significant measurement errors (Simar and Wilson, 2002).

By letting $\boldsymbol{y} = (y_1, \boldsymbol{y_a})$, where y_1 denotes the first output (milk) and $\boldsymbol{y}_a \in \mathbb{R}^{s-1}$ is a vector of the remaining outputs, the production technology $T(t)$ in (2.1) can be represented by the production function:

$$f_t(\boldsymbol{x}, \boldsymbol{y}_a) = max_{y_1} \{y_1 : (y_1, \boldsymbol{y_a}, -\boldsymbol{x}) \in \boldsymbol{T}(t)\} \quad (2.3)$$

where $f_t(\boldsymbol{x}, \boldsymbol{y}_a)$ is the largest output y_1 that can obtained under technology $T(t)$, given inputs $\boldsymbol{x}$ and outputs $\boldsymbol{y}_a$. Under the DEA formulation $T^e(t)$ given in (2.2), the production function in (2.3) becomes:

$$f_t^e(\boldsymbol{x}, \boldsymbol{y}_a) = max_{y_1,\mu} \ \{y_1: \sum_{i=1}^n \mu_{it} y_{1it} \geq y_1, \sum_{i=1}^n \mu_{it} \boldsymbol{y}_{ait} \geq \boldsymbol{y}_a, \tag{2.4}$$

$$\sum_{i=1}^n \mu_{it} \boldsymbol{x}_{it} \leq \boldsymbol{x}, \sum_{i=1}^n \mu_{it} = 1, \ \mu_{it} \geq 0, i \in N\}$$

The production function $f_t^e(\boldsymbol{x}, \boldsymbol{y}_a)$ in (2.4) is non-decreasing in $\boldsymbol{x}$, non-increasing in $\boldsymbol{y}_a$, and concave in $(\boldsymbol{x}, \boldsymbol{y}_a)$. In addition, this function satisfies $y_{1it} \leq f_t^e(\boldsymbol{x}_{it}, \boldsymbol{y}_{ait})$ for all $i \in N$. Thus, finding that $y_{1it} = f_t^e(\boldsymbol{x}_{it}, \boldsymbol{y}_{ait})$ implies that the i-th farm chooses its inputs and outputs in the production function. Alternatively, finding $y_{1it} < f_t^e(\boldsymbol{x}_{it}, \boldsymbol{y}_{ait})$ would mean that the i-th farm is technically inefficient, as its production choice is located below the production frontier.

The production function $f_t^e(\boldsymbol{x}, \boldsymbol{y}_a)$ in (2.4) corresponds to a static formulation. We now introduce dynamics in the analysis. Let $K_{it} \in \mathbb{R}_+$ be the amount of capital available to the i-th farm at time t. Capital evolves over time according to the state equation:

$$K_{it+1} = (1 - \delta) \ K_{it} + I_{it} \tag{2.5}$$

where $\delta \in (0,1)$ is the depreciation rate of capital and $I_{it} \in \mathbb{R}$ is the investment made by the i-th farm at time t. Equation (2.5) shows that capital increases (decreases) over time when investment I_{it} is larger (smaller) than capital depreciation, $\delta \ K_{it}$. In general, capital K_{it} contributes positively to the production process.

However, changes in capital can also create frictions in the production process and affect productivity. On that basis, we consider the case where the production frontier takes the form $y_{1it} = f_t(\boldsymbol{x}_t, K_{it}, DK_{it}, \boldsymbol{y}_{at})$ where $DK_t = K_t - K_{t-1}$. Capital K_{it} is treated as an input in the production process, meaning that $f_t(\boldsymbol{x}_t, K_{it}, DK_{it}, \boldsymbol{y}_{at})$ is non-decreasing and concave in K_{it}. In addition, the variable DK_{it} reflects the productivity effects of capital changes, capturing adjustment costs. Such effects can be positive, zero or negative. We note:

$$DK_{it} = DKp_{it} - DKm_{it} \tag{2.5'}$$

where $DKp_{it} = max\{0; K_{it} - K_{it-1}\} \geq 0$ represents increases in capital from one period to the next and $DKm_{it} = -min\,\{0; K_{it} - K_{it-1}\} \geq 0$ represents decreases in the absolute value of capital.

To the extent that adjustment costs arise when resources are used in the process of adapting to capital changes, productivity will be at its highest levels when capital changes little, i.e., when $|K_{it} - K_{it-1}| \approx 0$. In this context, there would be no adjustment cost when $|K_{it} - K_{it-1}|$ is small. However, when situations arise such that $|K_{it} - K_{it-1}| > 0$, adjustment costs are generated as resources are used to adapt to changes in capital. In this case, productivity will decline when $|K_{it} - K_{it-1}|$ increases. Thus, for a given $(\boldsymbol{x}_t, K_{it}, \boldsymbol{y}_{at})$, $f_t(DK_{it}, .)$ will have an inverted U-shape with respect to DK_{it} and reach its maximum point when $DK_{it} \approx 0$. In this context, we assume that the function $f_t(\boldsymbol{x}_t, K_{it}, DK_{it}, \boldsymbol{y}_{at})$ is concave in DK_{it}, and we modify equation (2.4) into the following DEA representation of the production function:

$$f_t^e(\boldsymbol{x}, K, DK, \boldsymbol{y}_a) = max_{y_1, \mu}\ \{y_1 \colon \sum_{i=1}^{n} \mu_{it} y_{1it} \geq y_1, \sum_{i=1}^{n} \mu_{it} \boldsymbol{y}_{ait} \geq \boldsymbol{y}_a, \tag{2.4'}$$

$$\sum_{i=1}^{n} \mu_{it} DKp_{it} \geq DKp, \sum_{i=1}^{n} \mu_{it} DKm_{it} \geq DKm, \sum_{i=1}^{n} \mu_{it} \boldsymbol{x}_{it} \leq \boldsymbol{x}, \sum_{i=1}^{n} \mu_{it} = 1,$$

$$\mu_{it} \geq 0, i \in N\},$$

where $DK_t = DKp_t - DKm_t = K_t - K_{t-1}$. Equation (2.4') captures the role of the adjustment costs. This equation distinguishes between DKp and DKm, allowing adjustments to have asymmetric effects between capital increases and capital decreases (e.g., as found by Oude Lansink and Stefanou (1997)).

As discussed in the introduction, we also introduce a production quota on the first output. Thus, we consider the case in which output y_{1it} (milk) is subject to a quota constraint

$$y_{1it} \leq Q_{it} \tag{2.6}$$

where Q_{it} is a quota that imposes an upper bound on the quantity of output y_{1it} that the i-th farm can produce at time t.

For the i-th farm at time t, profit is denoted as $\pi_{it} = p_{1it}\, y_{1it} + \boldsymbol{p}_{ait}\, \boldsymbol{y}_{ait} - \boldsymbol{w}_{it}\, \boldsymbol{x}_{it} - q_{it}\, I_{it}$, where $p_{1it} \in \mathbb{R}_+$ is the price of output y_{1it}, $\boldsymbol{p}_{ait} \in \mathbb{R}_+^{s-1}$ represents the prices of outputs $\boldsymbol{y}_{ait}$ and $\boldsymbol{w}_{it,} \in \mathbb{R}_+^m$ are the prices of the variable inputs $\boldsymbol{x}_{it}$ and q_{it}, and $\in \mathbb{R}_+$ is the price of investment I_{it}. Assume that the manager of the i-th farm wants to maximize his/her expected discounted profit over a τ-period planning horizon. His/her discounted profit is $\sum_{t=1}^{\tau} \beta^t \ \pi_{it}$, where $\beta \in (0,1)$ is a discount factor. Assume that imperfect information about the future (e.g., about future prices) is represented by random variables with a subjective probability distribution. Given equations (2.5) and (2.6) and using backward induction, the production choices made by the i-th farmer at time t can then be represented by Bellman's equation:

$$V_{it}(K_{it}, K_{it-1}) = max_{x_{it}, y_{ait}, I_{it}}\{p_{1it}\, f_t(\boldsymbol{x}_{it}, K_{it}, K_{it} - K_{it-1}, \boldsymbol{y}_{ait}) + \boldsymbol{p}_{ait}\, \boldsymbol{y}_{ait} - \boldsymbol{w}_{it}\, \boldsymbol{x}_{it} - q_{it}\, I_{it} + \beta\, E_{it}[V_{it+1}((1-\delta)\, K_{it} + I_{it}, K_{it})]: f_t(\boldsymbol{x}_{it}, K_{it}, K_{it} - K_{it-1}, \boldsymbol{y}_{ait}) \leq Q_{it}\} \quad (2.7)$$

where $V_{it}(\cdot)$ is the value function at time t and E_{it} is the expectation operator over the future, reflecting the information available to the i-th farmer at time t; $t = \tau, \tau - 1, \ldots, 2, 1$ (Bond and Meghir, 1994). The constrained optimization problem in (2.7) can be written using the Lagrangean:

$$L_{it} = p_{1it}\, f_t(\boldsymbol{x}_{it}, K_{it}, DK_{it}, \boldsymbol{y}_{ait}) + \boldsymbol{p}_{ait}\, \boldsymbol{y}_{ait} - \boldsymbol{w}_{it}\, \boldsymbol{x}_{it} - q_{it}\, I_{it} \quad (2.8)$$

$$+ \beta\, E_{it}[V_{it+1}((1-\delta)\, K_{it} + I_{it}, K_{it})] + \lambda_{it}\, [Q_{it} - f_t(x_{it,}, K_{it}, DK_{it}, \boldsymbol{y}_{ait})]$$

where $DK_{it} = K_{it} - K_{it-1}$ and $\lambda_{it} \in \mathbb{R}_+$ is the Lagrangean multiplier representing the shadow price of quota Q_{it} or the quota rent. Under differentiability and interior solutions, the first-order necessary conditions for the choice of inputs $\boldsymbol{x}_{it}$, outputs $\boldsymbol{y}_{ait}$ and investment I_{it} are

$$(p_{1it} - \lambda_{it}) \frac{\partial f_t}{\partial x_{it}} = \boldsymbol{w}_{it} \quad (2.9a)$$

$$-(p_{1it} - \lambda_{it}) \frac{\partial f_t}{\partial \boldsymbol{y}_{ait}} = \boldsymbol{p}_{ait} \quad (2.9b)$$

$$\beta\, E_{it} \frac{\partial V_{it+1}}{\partial K_{it+1}} = q_{it}. \quad (2.9c)$$

Equations (2.9a) and (2.9b) are familiar profit-maximization conditions, stating that for inputs $\boldsymbol{x}_{it}$ and outputs $\boldsymbol{y}_{ait}$, the marginal value product equals the corresponding market price. As discussed below, equation (2.9c) represents the decision rule related to investment and capital formation. Given $DK_{it} = K_{it} - K_{it-1}$, applying the envelope theorem to (2.7) with respect to K_{it} and K_{it-1} gives:

$$\frac{\partial V_{it}}{\partial K_{it}} = (p_{1it} - \lambda_{it})\left(\frac{\partial f_t}{\partial K_{it}} + \frac{\partial f_t}{\partial DK_{it}}\right) + \beta\, E_{it}\frac{\partial V_{it+1}}{\partial K_{it+1}}(1-\delta) + \beta\, E_{it}\frac{\partial V_{it+1}}{\partial K_{it}}, \tag{2.10}$$

and

$$\frac{\partial V_{it}}{\partial K_{it-1}} = -(p_{1it} - \lambda_{it})\frac{\partial f_t}{\partial DK_{it}}$$

or, by changing time from t to $(t+1)$,

$$\frac{\partial V_{it+1}}{\partial K_{it}} = -(p_{1it+1} - \lambda_{it+1})\ \frac{\partial f_{t+1}}{\partial DK_{it+1}}. \tag{2.11}$$

Substituting (2.9c) into (2.10) yields

$$(p_{1it} - \lambda_{it})\left(\frac{\partial f_t}{\partial K_{it}} + \frac{\partial f_t}{\partial DK_{it}}\right) = \frac{\partial V_{it}}{\partial K_{it}} - q_{it}\,(1-\delta) - \beta\, E_{it}\frac{\partial V_{it+1}}{\partial K_{it}} \tag{2.12}$$

Let $e_{it+1} \equiv \frac{\partial V_{it+1}}{\partial K_{it+1}} - E_{it}\frac{\partial V_{it+1}}{\partial K_{it+1}}$ satisfying $E_{it}(e_{it+1}) = 0$, and let $\beta = 1/(1+r)$, where $r \in \mathbb{R}_+$ is the interest rate. Then, using (2.9c) and (2.11), equation (2.12) becomes:

$$(p_{1it} - \lambda_{it})\left(\frac{\partial f_t}{\partial K_{it}} + \frac{\partial f_t}{\partial DK_{it}}\right) = c_{it} \tag{2.13a}$$

where

$$c_{it} = r\, q_{it-1} + \delta\, q_{it} - (q_{it} - q_{it-1}) + \frac{1}{1+r}\ E_{it}\left[(p_{1it+1} - \lambda_{it+1})\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right] + e_{it}. \tag{2.13b}$$

The term c_{it} in equation (2.13b) is the user cost of capital for the i-th farm at time t (see Hall and Jorgenson (1967)). In this context, equation (2.13a) characterizes the decision rule for capital, stating that the marginal value of capital K_{it} (the left-hand side of (2.13a)) equals the user cost of capital c_{it}. According to (2.13b), the user cost of capital is the sum of five components: $r\, q_{it-1}$, reflecting the interest cost of investment; $\delta\, q_{it}$, measuring the depreciation cost; $-(q_{it} - q_{it-1})$, representing speculation related to investment price changes; $\frac{1}{1+r} E_{it}\left[(p_{1it+1} - \lambda_{it+1}) \frac{\partial f_{t+1}}{\partial DK_{it+1}}\right]$, capturing the adjustment cost; and e_{it}, which is an error term with a mean of zero. The term $\frac{1}{1+r} E_{it}\left[(p_{1it+1} - \lambda_{it+1}) \frac{\partial f_{t+1}}{\partial DK_{it+1}}\right]$ reflects the role of the adjustment cost since $\frac{\partial f_{t+1}}{\partial DK_{it+1}} = 0$ in the absence of an adjustment cost. In addition, without an adjustment cost, (2.13b) reduces the user cost of capital, as discussed in Hall and Jorgenson (1967).

Consider the case where $(p_{1it} - \lambda_{it}) > 0$. As $f_t(K_{it},\cdot)$ is concave in K_{it}, $(p_{1it} - \lambda_{it})\frac{\partial f_t}{\partial K_{it}}$ can be interpreted as the demand for capital. Then, any decrease (increase) in the user cost of capital c_{it} would provide an incentive (disincentive) to hold capital. It follows from (2.13a)-(2.13b) that capital K_{it} will increase when the interest rate r decreases, the depreciation rate δ decreases, the price of the investment increases $(q_{it} - q_{it-1}) > 0$, $\frac{1}{1+r} E_{it}\left[(p_{1it+1} - \lambda_{it+1})\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right] < 0$ or when $e_{it} < 0$. When $(p_{1it+1} - \lambda_{it+1}) > 0$, note that $\frac{1}{1+r} E_{it}\left[(p_{1it+1} - \lambda_{it+1})\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right] < 0\ (> 0)$ when $\frac{\partial f_{t+1}}{\partial DK_{it+1}} < 0\ (> 0)$, i.e., when the next-period productivity effect of the change in capital $DK_{it+1} = K_{it+1} - K_{it}$ is negative (positive). Finally, note that $e_{it} < 0\ (> 0)$ when $\frac{\partial V_{it}}{\partial K_{it}} < (>)\ E_{it-1}\frac{\partial V_{it}}{\partial K_{it}}$, i.e., when the marginal value of capital K_{it} is lower (higher) than expected.

Equation (2.13b) involves expectations about the future. The previous literature has explored alternative ways agents can form their expectations. The main assumptions are that the expectations are rational, naïve and quasi-rational (Muth, 1961; Nerlove and Fornari, 1998, Chavas, 2000). Rational expectations (Muth, 1961) assume that the forecasted outcomes do not differ systematically from the market equilibrium; that is, agents do not make systematic errors when predicting the future. In the case of naïve expectations, agents assume that the future values of the market variables will be the same as observed in the last period. Finally, the quasi-rational expectation scheme assumes that agents form their expectations based on past observations (Nerlove and Fornari, 1998). Chavas (2000) presented evidence that naïve expectations are the most common form of expectations on livestock farms. On that basis, we assume naïve expectations about market prices. However, we assume rational expectations for adjustment costs, meaning that farmers are able to properly anticipate their adjustment costs.

By assuming naïve expectations for output prices and the shadow price of quota and rational expectations for adjustment costs, we have $E_{it}\left[(p_{1it+1}-\lambda_{it+1})\ \frac{\partial f_{t+1}}{\partial DK_{it+1}}\right]=\left[(p_{1it}-\lambda_{it})\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right]$ and equations (2.13a)-(2.13b) become:

$$(p_{1it}-\lambda_{it})\left(\frac{\partial f_t}{\partial K_{it}}+\frac{\partial f_t}{\partial DK_{it}}\right)=r\ q_{it-1}+\delta\ q_{it}-(q_{it}-q_{it-1})+\frac{1}{1+r}\ \left[(p_{1it}-\lambda_{it})\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right]+e_{it} \quad (2.14)$$

Equation (2.14) represents the optimal investment under production quotas and an adjustment cost. The effect of the production quota Q_{it} on the i-th farm at time t is given by λ_{it}, the Lagrange multiplier measuring the farmer's marginal willingness to pay to relax the quota Q_{it} by one unit. In addition, the effect of the adjustment cost on the optimal investment is given by $\frac{\partial f_{t+1}}{\partial DK_{it+1}}$ in (2.14). Equation (2.14) provides the basis for our empirical investigation of farm investment behavior.

As seen in (2.14), many factors affect capital formation. Under a "soft landing" policy, we expect the shadow price of quota λ to decline in response to an increase in quota Q, providing an incentive to expand production. However, this incentive may be muted by the presence of adjustment costs. In addition, other factors also play a role (including the evolving market price of milk). As a result, the effects of the quota termination and the "soft landing" policy on farm investments are difficult to know a priori. In addition, such effects may vary across farms (e.g., as productivity can vary across farm types). Our analysis is intended to provide new information on these issues.

2.3 Data and methodology

- **Data**

Brittany is a dynamic dairy region in Northwest France. Our analysis examines the production and investment decisions of a sample of farmers in Ille-et-Vilaine, a small sub-region of Brittany where milk production is the dominant farm activity. In the Ille-et-Vilaine sub-region, most farms specialize in milk production. Our analysis relies on data collected annually by an accounting firm, the Centre de Conseil et d'Expertise Comptable of IIle-et-Vilaine. First, the data were evaluated for their accuracy. We removed the observations that appeared to include data recording errors or incomplete records. Second, our analysis focuses on farms that kept records over time. As a result, our sample involves strongly balanced panel data on 616 farms observed annually over the period 2005-2014.[4] Thus, the data used in our empirical analysis include 5,536 observations.

As shown in table 2.1, the sample farms have on average 73.6 hectares (ha) of utilized agricultural area (UAA), 1.89 full-time equivalent labor units, and 51.5 dairy cows producing 7,136 liters of milk per cow. Table 2.1 also shows that our sample farms are larger on average than those included in the exhaustive Agricultural Census population of the same sub-region in terms of UAA and labor use, but they are similar in terms of the number of cows and have a higher milk yield. Our sample probably includes farms that are more commercially-oriented (and are more likely to use bookkeeping).

TABLE 2.1:Descriptive Statistics of the Sample used Compared to those of the Agricultural Census population.

	Sample used (Sample average from 2005-2014)	Total farm population in the same sub-region as our sample (Population's average in 2010; Agricultural Census)
Structural variables		
Milk produced (liters)	370,560	356,110
UAA (ha)	73.6	63
Number of dairy cows	51.5	52
Number of labor full-time equivalent units	1.89	1.7
Milk yield (liters / cow)	7,136	7,036
Number of observations	616	3,248

Source: The authors, based on CER FRANCE Ille-et-Vilaine and Agreste (2010)

The data used in our analysis include two agricultural outputs; milk production (y_{1it}) is measured by milk sales, and other production $(\boldsymbol{y}_{ait})$ is measured by the sales of other types of production including crops and other animal sales deflated by the price index of agricultural products using 2010 as the base year. Additionally, the analysis includes three categories of

[4] 98.7% of the sampled farms have data available for every year; the remaining 1.3% have data available for all years but one.

inputs: intermediate inputs, labor and land ($\boldsymbol{x}_{it}$). Several measures have been used in the literature to proxy labor, including working hours, numbers of employees and quality-adjusted labor (Syverson, 2011). The agricultural sector is particular in the sense that labor is often self-employed family labor, making it difficult to measure wages or working hours. In our study, we measure labor by attributing 2200 hours per year for family workers and 1800 hours per year for hire employees (Bakucs et al., 2013). As it is commonly used in the literature, UAA is used to measure land in this study. We assume that land quality is homogeneous in the Ille-et-Villaine sub-region. Additionally, we assume that land quality is constant over the period studied. Intermediate inputs are proxied by operational expenses, i.e., the costs related to the farming operations, including costs for purchased animal feed, straw litter, and fuel and veterinary and animal reproduction costs. Operational expenses are deflated by the price index of the goods and services consumed during the agricultural processes using 2010 as the base year. Finally, we measure physical capital K as the real value of the capital stock. Capital includes building capital, machinery capital, livestock capital, and other capital (computers, cars, etc.). The real value of capital is obtained by deflating its nominal value by the corresponding price index using 2010 as the base year.

- **Empirical approach**

Our empirical analysis proceeds in several steps. For the first step, we use DEA to estimate the production function $f_t^e(\boldsymbol{x}, K, DK, \boldsymbol{y}_a)$ in (2.4'). The DEA estimates provide a flexible representation of the technology under adjustment costs (as captured by $DK_t = K_t - K_{t-1}$) and allow for technological change (as the production function can change over time t). As discussed above, equation (2.4') distinguishes between DKp_{it} and DKm_{it}, allowing for the asymmetric effects of capital increases and capital decreases. The summary statistics of the data used to estimate the production function are presented in table 2.2.

TABLE 2.2: Summary Statistics of the Variables used to define the Production Function.

	Mean	Standard deviation	Min	Max	Number of observations
Milk sales (liters)	357,652	152,053	22,489	1,299,236	5,536
Total outputs sales (€)	182,264	91,217	19,026	618,825	5,536
UAA (ha)	73.5	30	14.5	231	5,536
Total labor (hours)	4,172	1,535	2,200	11,000	5,536
Total capital (€)	213,919	124,527	23,283	1,171,219	5,536
Intermediate inputs (€)	63,068	52,897	1,429	354,125	5,536

Source: The authors, based on CER FRANCE Ille-et-Vilaine

For the second step, we use the DEA estimates to evaluate the marginal products $\frac{\partial f_t}{\partial K_{it}}$ and $\frac{\partial f_t}{\partial DK_{it}}$ for all (i,t). The marginal product $\left(\frac{\partial f_t}{\partial K_{it}}\right)$ is the shadow value of capital K_{it}, and the term capturing the adjustment cost $\left(\frac{\partial f_t}{\partial DK_{it}}\right)$ is the shadow value of DKp_{it} minus the shadow value of DKm_{it} (since $DK_{it} = DKp_{it} - DKm_{it}$, as shown in (2.5')). For the third step, using the estimates of $\frac{\partial f_t}{\partial K_{it}}$ and $\frac{\partial f_t}{\partial DK_{it}}$ obtained in step 2, we can solve equation (2.14) for λ_{it}, the shadow price of the quota for the i-th farm at time t. Evaluated at its expected value (where $E_{t-1}(e_t) = 0$), the estimated value of λ_{it} for each farm and period is:

$$\widehat{\lambda_{it}} = max\left\{0, \left\{p_{1it} - \frac{r\, q_{it-1} + \delta\, q_{it} - (q_{it} - q_{it-1})}{\left(\left(\frac{\partial f_t}{\partial K_{it}} + \frac{\partial f_t}{\partial DK_{it}}\right) - \frac{1}{1+r}\frac{\partial f_{t+1}}{\partial DK_{it+1}}\right)}\right\}\right\} \quad (2.15)$$

The data used for the computation of the shadow price of quota in (2.15) include the output price (p_{1it}), which is the sale price of milk for the i-th farm in period t[5]; the investment price (q_{it}), which is proxied by the national price index of the investment goods using 2010 as the base year in period t[6]; the capital depreciation rate (δ), which is supposed to be equal to 0.15; and the official annual real interest rate provided by the European Central Bank, called

[5] This was deflated by the price index of the agricultural products using 2010 as the base year.

[6] http://www.bdm.insee.fr/bdm2/affichageSeries;jsessionid=CC16B3C020F8B1406755EA46FF66361B?idbank=001664236&bouton=OK&codeGroupe=1466

EURIBOR, which uses 12 months for the actualization rate (r_t) in period t[7]. The marginal product of capital $\left(\frac{\partial f_t}{\partial K_{it}}\right)$ and the term capturing the adjustment cost $\left(\frac{\partial f_t}{\partial DK_{it}}\right)$ were obtained in step 2.

The summary statistics for the shadow price of the quota (obtained from equation (2.15)) are presented in table 2.3. Figure 2.2 shows the evolution of the average shadow price of milk quotas per year. According to table 2.3, the estimated shadow price of the quota has a standard deviation of 361.95, revealing much heterogeneity in quota rents. There is heterogeneity across farms (see table 2.3) as well as across years (see Figure 2.2).

TABLE 2.3: Summary Statistics of the Variables used to Compute the Shadow Price of the Quota.

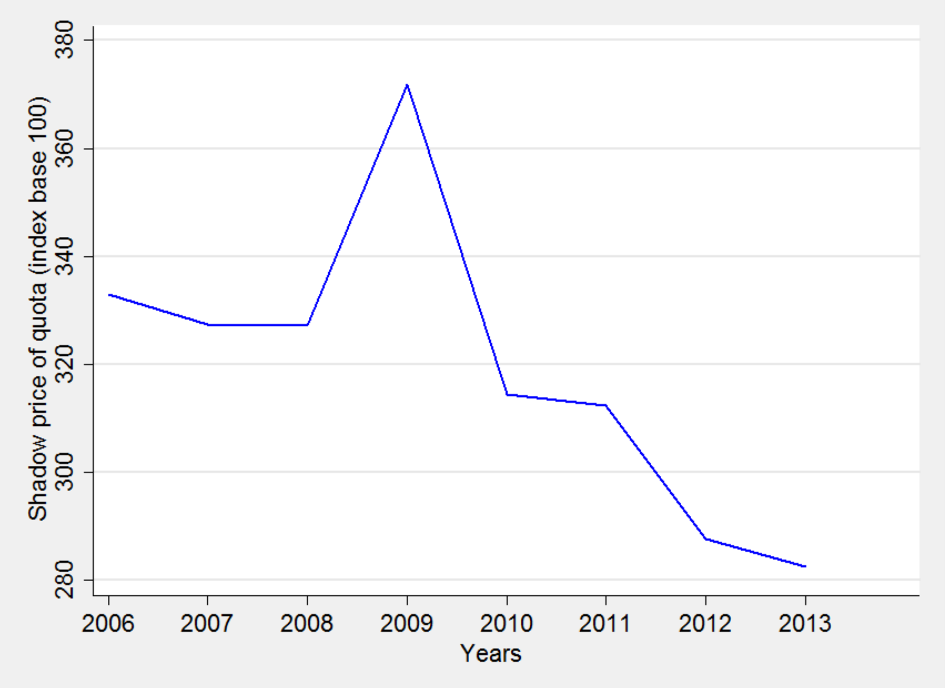
	Mean	Standard deviation	Min	Max	Number of observations
Shadow value of DK_{it}	1.35	3.84	-12.35	85.79	5,536
Shadow value of DKp_{it}	-0.73	1.49	-38.91	0	5,536
Shadow value of DKm_{it}	-2.08	4.59	-95.77	0	5,536
Price index of investment (base 100)	98.27	6.36	87.4	106.1	5,536
Annual real interest rate	0.73	1.19	-0.89	2.95	5,536
Milk price (€ per 1000 liters)	329.59	34.69	251.94	482.85	5,536
Shadow price of the quota (index base 100)	319.47	361.95	0	22,739.8	5,536

Note 1: The shadow value of DKp_{it} and DKm_{it} are, respectively, the marginal product of a capital increase $\left(\frac{\partial f_t}{\partial DKp_{it}}\right)$ and the marginal product of a capital decrease $\left(\frac{\partial f_t}{\partial DKm_{it}}\right)$, computed using DEA. The term capturing the adjustment cost $\left(\frac{\partial f_t}{\partial DK_{it}}\right)$ is the shadow value of DKp_{it} minus the shadow value of DKm_{it} (since $DK_{it} = DKp_{it} - DKm_{it}$ from (5')).

Source: The authors, based on CER FRANCE Ille-et-Vilaine

[7] http://fr.global-rates.com/taux-de-interets/euribor/taux-de-interets-euribor-12-mois.aspx

FIGURE 2.2: Evolution of the average shadow price of the milk quotas per year.



Source: The authors, based on CER FRANCE Ille-et-Vilaine

Note that the marginal products $\left(\frac{\partial f_t}{\partial K_{it}}\right)$ and $\left(\frac{\partial f_t}{\partial DK_{it}}\right)$ in (2.15) can vary across farms. Thus, the quota rent $(\widehat{\lambda_{it}})$ measured in (2.15) can also vary across farms. This implication raises questions about the heterogeneity of quota rents across farms. For the fourth step, we evaluate the nature of this heterogeneity, which is done by considering the following econometric model:

$$\lambda_{it} = \alpha_0 + \alpha_1 \lambda_{it-1} + \alpha_2 Spe_{it} + \alpha_3 herd\ size_{it} + \alpha_4 age_{it} + \alpha_5 LaborProd_{it} + \alpha_6 Capital\ stock\ per\ LU_{it} + \alpha_7 Cost\ of\ work\ outsourcing\ per\ LU_{it} + \alpha_8 Share\ of\ fodder\ maize\ in\ forage\ area_{it} + v_{it} \tag{2.16}$$

where $\boldsymbol{\lambda_{it}}$ is obtained from (2.15) for the i-th farm at time t. The explanatory variables in (2.16) are specified to give us some insights on the factors affecting the quota rents. The variable $\boldsymbol{age_{it}}$ in (2.16) is the age of the manager in period t, capturing the effect of intertemporal preferences linked to the farmer's life cycle. This variable also partially controls for how the French administration prioritized quota attribution among farmers (as young farmers are given some priority)[8]. The variable $\boldsymbol{herd\ size_{it}}$ in (2.16) is the number of dairy cows on the i-th farm in period t, capturing the role of farm size (as the French administration gave some priority to small farms in quota allocations)[9].

The variable $\boldsymbol{Spe_{it}}$ in (2.16) is the degree of dairy specialization in period t, proxied by the ratio of the milk gross margin to the total gross margin, and the variable $\boldsymbol{Share\ of\ fodder\ maize\ in\ forage\ area_{it}}$ captures the level of farm intensification. These two variables capture any possible heterogeneous effects of EU policy reform on farms' investment incentives, providing information on how policy reform can affect structural changes in the Brittany dairy sector. It is expected that farms with a high level of specialization and/or intensification may have greater incentives to invest than farms with a low level of specialization and/or intensification.

The variable $\boldsymbol{LaborProd_{it}}$ in (2.16) is an indicator of the labor productivity of a farm and is proxied by the total net production per work unit (farmers), allowing us to capture heterogeneity in terms of labor productivity. Thereby, in case there is no quota constraint, farms with high labor productivity could produce more milk than farms with low labor productivity, ceteris paribus. Therefore, farms with high labor productivity should have a higher shadow cost for the quota than farms with low labor productivity.

The variable $\boldsymbol{Capital\ stock\ per\ LU_{it}}$ in (2.16) captures the role of capital intensity and its effect on the quota rent. This variable represents heterogeneous technologies in the farm sample. Such technological heterogeneity may imply that different investment strategies are used to adapt to the new policy, and hence, there are different incentives for holding capital. The documentation of this pattern for French dairy farmers is an important result of this study. Of special interest is the heterogeneous effect of EU policy reform on farms investment incentives because this new knowledge will allow the structural changes in the Brittany dairy sector to be anticipated.

The variable $\boldsymbol{Cost\ of\ work\ outsourcing\ per\ LU_{it}}$ in (2.16) captures the possible choices of farms between investing in new machines and sharing machines through

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[8] France quotas are administratively managed, which differs from other European countries, such as England, which opts to use a liberal approach of tradeable quota management, and Germany, which has decided to liberalize by using limits as well.

[9] According to the French administration, "small farms" refers to farms for which the milk quota is less than or equal to 170.000 liters. Source: DGPAAT, 2014. Available on : https://info.agriculture.gouv.fr/gedei/site/bo-agri/historique/annee-2014/semaine-31#

outsourcing services provided by cooperatives. The use of these outsourcing services could reduce the incentives of farms to hold capital.

Finally, in (2.16), we assume that the shadow price of the quota depends on its past value λ_{it-1}, reflecting possible temporal adjustments. Equation (2.16) also includes the error term $\boldsymbol{v_{it}} \equiv s_i + w_{it}$, where s_i is a farm-specific effect and w_{it} captures other unobservable factors.

Equation (2.16) is estimated using the generalized method of moments (GMM) to correct for possible endogeneity. Indeed, we consider that $herd\ size_{it}$ is an endogenous variable because herd size can be simultaneously adjusted with other variables. Likewise, $Capital\ stock\ per\ LU_{it}$ and $Cost\ of\ work\ outsourcing\ per\ LU_{it}$ are both endogenous because farms can simultaneously adjust farm capital stock, herd size (Livestock Unit) and the use of outsourced work. As instruments, we use other variables of the model in period t that are considered to be exogenous: Spe_{it},age_{it}, $LaborProd_{it}$, λ_{it-1}, $Share\ of\ fodder\ maize\ in\ forage\ area_{it}$ and the endogenous variables lagged over two periods ($herd\ size_{it}$, $Capital\ stock\ per\ LU_{it}$, and $Cost\ of\ work\ outsourcing\ per\ LU_{it}$), assuming that they are exogenous. The summary statistics of the data used for the estimation of (2.16) are presented in table 2.4.

TABLE 2.4: Summary Statistics of the Variables used in the estimation of the determinants of the shadow price of the quota.

	Mean	Standard deviation	Min	Max	Number of observations
Degree of specialization	0.63	0.13	0.01	1	5,536
Herd size (number of dairy cows)	51.5	18.1	7.6	150	5,536
Age (years)	42.4	8.8	16	67	5,536
Labor productivity	131,173	60,528	28,742	983,969	5,536
Capital stock per LU (€)	7,166	3,099	1,799	39,905	5,536
Cost of outsourcing work per LU (€)	166	78	0	862	5,536
Share of fodder maize in the forage area (percent)	47.7	15.3	0	100	5,536

Source: The authors, based on CER FRANCE Ille-et-Vilaine

2.4 Results

- **Value of the shadow price of the quota**

As noted above, one of the contributions of this article is that it accounts for adjustment costs in the evaluation of the shadow price of the quota. Table 2.5 reports the estimates of the adjustment costs as measured by the elasticity $\frac{\partial \ln(f_t)}{\partial \ln(|DK_{it}|)}$. Table 2.5 shows that, on average, the elasticity $\frac{\partial \ln(f_t)}{\partial \ln(|DK_{it}|)}$ is -11.9% per year. When capital is increasing (the expanding regime), the elasticity is on average -3.2%, and it is -8.7% when capital is decreasing (the contracting regime). These estimates mean that the adjustment costs are asymmetric (e.g., as found by Oude Lansink and Stefanou (1997)), indicating that it is easier for a producer to downsize the operation during hard times than it is to expand during prosperous times. Several studies have also found there are higher adjustment costs for capital during contraction phases (e.g., Lansink (1997) analyzed cash crop farms in Germany, and Chang and Stefanou (1988) analyzed Pennsylvania dairy farms).

TABLE 2.5: Adjustment costs as measured by the Elasticity $\frac{\partial \ln(f_t)}{\partial \ln(|DK_{it}|)}$.

	Mean	Standard deviation	Min	Max	Number of observations
Expanding regime (positive investment)	-0.032	0.157.	-4.119	0	5,536
Contracting regime (negative investment)	-0.087	0.30	-9.919	0	5,536
Total	-0.119	0.33	-9.919	0	5,536

Source: The authors, based on CER FRANCE Ille-et-Vilaine

In tables 2.6 and 2.7, we compare farms having higher adjustment costs to farms having lower adjustment costs. More precisely, for farms undergoing capital changes, we compare the first quartile of farms having higher adjustment costs to the third quartile of farms having lower adjustment costs. This comparison relies on several farms characteristics and is made at the beginning of the period (2006) and at the end of the period (2013). Table 2.6 shows the results for the t-test for the equality of means. On average, in 2006, farms having higher adjustment costs also have higher capital stock per labor unit (LU) (meaning that they have higher capital intensity), a higher share of fodder maize in the forage area (meaning that it is more profitable (considering only the adjustment cost) to not have an intensive production system), and head farmers that are older than farms having lower adjustment costs. Likewise, table 2.7 shows that, in 2013, on average, farms having higher adjustment costs also have higher capital stock per LU and a lower cost for work outsourcing per LU, meaning that outsourcing work decreases the adjustment cost. However, in contrast to the results for 2006, farms have a smaller share of fodder maize in the forage area, meaning that in 2013, it was more profitable (considering only the adjustment cost) to become an intensive farm.

TABLE 2.6: Descriptive Statistics: Mean comparison of groups of farms having higher adjustment costs (3rd quartile) and farms having lower adjustment costs (1st quartile) in 2013.

VARIABLES	Lower Quartile (25%)		Upper Quartile (75%)		t-test (equality of means)
	Mean	Standard deviation	Mean	Standard deviation	
Degree of specialization	0.58	0.12	0.56	0.13	
Herd size (number of dairy cows)	57.6	18.4	54	17.6	
Age (years)	44.3	8.7	46	7.9	
Labor productivity	104,818	36,986	110,711	43,333	
Capital stock per LU (€)	7,127	2,891	8,348	4,234	***
Cost of outsourcing work per LU (€)	183	76	165	85	*
Share of fodder maize in the forage area (percent)	44.7	14.7	40.5	16.5	**
Total adjustment rate	-1.7	1.2	-56	49.1	***
Number of farms	103		102		

*Notes: *, **, *** is significance at the 10, 5, 1 percent level, respectively. The t-test is a test for the equality of means.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

TABLE 2.7: Descriptive Statistics: Mean comparison of groups of farms having higher adjustment costs (3rd quartile) and farms having lower adjustment costs (1st quartile) in 2006.

VARIABLES	Lower Quartile (25%) Adjustment Costs		Upper Quartile (75%) Adjustment Costs		t-test (equality of means)
	Mean	Standard deviation	Mean	Standard deviation	
Degree of specialization	0.70	0.14	0.68	0.17	
Herd size (number of dairy cows)	46.3	17.4	45.7	17.2	
Age (years)	36.9	8.37	39.3	7	**
Labor productivity	148,512	87,577	157,359	72,493	
Capital stock per LU (€)	6,267	2,709	7,028	2,669	**
Cost of outsourcing work per LU (€)	166.4	68.7	162.7	68.8	
Share of fodder maize in the forage area (percent)	39.9	13.1	43.9	15.1	**
Total adjustment rate	-1.5	1	-63.9	112.1	***
Number of farms	84		83		

*Notes: *, **, *** is significance at the 10, 5, 1 percent level, respectively. The t-test is a test for the equality of means.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

Our analysis indicates that considerable heterogeneity exists in the shadow price of the quota. Indeed, table 2.3 shows that the shadow price is on average 319.47 with a large standard deviation, revealing that considerable heterogeneity exists in the sample. This heterogeneity exists both over time and across farms. Figure 2.2 reports the evolution of the average shadow price of the quota for the period 2006-2013, documenting considerable heterogeneity over time. Except for a peak in 2009, Figure 2.2 shows that the average shadow value of the milk quotas has a downward trend over time. In addition, the decline in the average shadow price of the quotas is steady for the period 2009-2013. This result is consistent with a "soft landing" policy.[10] Indeed, the quota system prevented EU producers

[10] Note that this result is robust. We conducted a sensitivity analysis using different measures of real interest rates (evaluating constant versus variable real interest rates). The "soft landing" result held under these alternative measures.

from expanding milk production, and the increasing trend in the quota, by 2% in 2008/2009 and then 1% per year until 2015, allowed farmers to gradually expand their dairy operations. Such a gradual expansion can also be seen in Appendice Figure 2.3, showing that farmers invested in livestock in 2010 (two years after the announcement of the end of dairy quotas) and then started to invest more in machinery and buildings after 2011. Similar results apply to the evolution of the reproduction costs (as showed in Appendice Figure 2.4). In general, the decreasing trend in the shadow price of the quota after 2009 reflects changing investment incentives for dairy farms that were associated with the "soft landing" policy. The results also reflect a decreasing trend in milk prices between 2009 and 2013. Indeed, milk prices decreased by 16.1% in 2010, by 3.8% in 2012 and by 4% in 2013. Such factors help explain the heterogeneity in the shadow price of the quota over time. What about heterogeneity across farms? This topic is addressed in the next section.

- **Sources of heterogeneity**

As noted above, the economic effects of the "soft landing policy" associated with the progressive elimination of the EU quotas on farms remain poorly understood. This section explores two questions. Are the effects of the quota elimination homogeneous across farms? If not, how do the results vary for different farm types? Estimating equation (2.16) provides answers to these questions.

Table 2.8 reports the regression results from estimating equation (16) by GMM. We use GMM to address possible endogeneity issues. We checked the validity of the instruments. The Sargan test of over-identifying the restrictions does not reject the null hypothesis of orthogonality at the 10% significance level, indicating that the instruments are valid. Table 2.8 shows several results. The coefficient α_1 is nonsignificant, meaning that our structural model already captures the dynamics of the shadow price of quota. The coefficient α_2, which is related to specialization, is positive and significant. The shadow price of the quota is higher for specialized dairy farms, indicating that the quota constraint was more binding for more specialized dairy farms. The coefficient α_3, capturing the role of farm size, is positive but nonsignificant. Table 2.8 shows that age has a negative and statistically significant effect on the quota rent, indicating that the impact of the quota varies with the farmer's life cycle. The coefficient α_5, which is related to labor productivity, is positive and significant, meaning that the shadow price of the quota is higher for farms having higher labor productivity. This result may indicate that management skills jointly affect farm productivity and the shadow price of the quota constraints. The coefficients α_6, capturing capital intensity, is negative but it is not statistically significant. Likewise, the coefficient α_8, reflecting the level of farm intensification, is negative but nonsignificant.

TABLE 2.8: Regression Results of the Econometric Model.

	Dependent variable ($\boldsymbol{\lambda_{it}}$)	
	(1)	(2)
$\lambda_{(it-1)}$	0.00125 (0.00722)	0.000222 (0.00723)
Spe	93.70*** (31.06)	73.34** (30.85)
Herd size	0.0220 (0.195)	
Age	-0.755* (0.386)	-0.616* (0.373)
LaborProd	0.000172*** (5.45e-05)	0.000186*** (5.45e-05)
Capital stock per LU_{it}	-0.0789 (0.121)	
Cost of work outsourcing per LU_{it}	0.0724 (0.0485)	0.0695 (0.0484)
Share of fodder maize in forage $area_{it}$	-0.0820 (0.220)	
Dummy herd size		22.24* (13.04)
Dummy capital stock per LU		-15.81* (9.551)
Dummy share of fodder maize in forage area		-21.83* (13.28)
Constant	264.9*** (37.72)	286.2*** (33.86)
Number of farm-year observations	3,449	3,449
Number of farms	616	616
Sargan statistic	0.3734	0.6832
Instruments: lagged variables in period	t and t-2	t and t-2

*Notes: Robust standard errors in parentheses. *, **, ***: significance at the 10, 5, 1 percent level, respectively.*
(1) Estimation with continuous variables
(2) Estimation with continuous variable and a dummy variable for Herd size, Capital stock per LU and Share of fodder maize in the forage area.

Source: The authors, based on CER FRANCE Ille-et-Vilaine

We also examine whether there may be categorical differences in the determination of the quota rents by introducing the following dummy variables in the model: $DummyHerdSize$ (= 1 for herds with more than 76 cows), $DummyCapital\,Stock$ (= 1 when capital stock exceeds 7,600€ per LU), and $DummyShare\ of\ FodderMaize$ (= 1 when the fodder area exceeds 23%). Table 2.8 shows that $HerdSize$ has a positive effect on the quota rent but that $CapitalStock$ and $Share\ of\ FodderMaize$ have negative effects. These results document that the cost of the quota can vary significantly across farms.

2.5 Conclusion and implications

This article has investigated the economic effects of a "soft landing policy" associated with the progressive elimination of EU dairy quotas on French dairy farm investment during the period 2005-2014. We studied the case of the Brittany dairy sector. Our main contribution is that we improve our understanding of how farmers react to this policy shift, that is, the impacts on farmers' production adjustments and investment behavior. This analysis uses a neoclassical model of optimal capital accumulation in the presence of a milk quota and adjustment costs. This study evaluates the shadow price of the milk quota and studies its determinants. This article sheds new light on the linkages between investment incentives and dynamic adjustments to market and policy changes. This study also documents the heterogeneity of farmers' responses to policy reform both over time and across farms and structural changes.

First, we find a decreasing trend in the shadow price of the quota between 2009 and 2013 (see Figure 2.2). This result is consistent with a "soft landing" policy that allows farmers to slowly adjust to the elimination of the quota.

Second, the results reveal farm heterogeneity, showing that the quota constraint was more binding on more specialized dairy farms. This result means that relaxing this constraint favors specialized dairy farms. We uncovered evidence that the quota effects vary with the farmer's age and his/her life cycle. We also found that farms with high labor productivity have a higher shadow cost of the quota than farms with low labor productivity, underlining possible interactions between managerial ability and adjustments to policy shift. Finally, we found heterogeneity in the quota effects across farms depending on herd size, capital intensity (capital stock per LU) and intensification (share of fodder maize in the forage area). This result reveals that farms with higher capital intensity, farms with higher production systems and small farms have a greater incentive to hold capital.

From a policy viewpoint, our investigation suggests that policy reform affects the evolving structure of agriculture. We showed that the EU quota elimination has contributed to the trend toward larger farms, more capital intensive farms and more specialized dairy farms. However, the end of the dairy quota is not the sole driver of farm structure. The price level of milk and volatility could strongly influence risk perception and price anticipation. Indeed, the financial crisis in 2009 showed that milk prices can drop to a very low level and can make dairy farmers have doubts about their future. In this context, extreme milk price episodes can also speed up the structural changes that may follow the abolition of the milk quota (Frick and Sauer, 2017). Future studies are needed to explore such issues.

The results have important policy implications. Indeed, milk quotas were originally instated, in part, to protect farmers from rapid structural changes in agriculture (e.g., increasing farm sizes, frequent farm exits, and shifts in production to more productive areas). If the objective is to preserve traditional farming structures, then regional policy measures need to focus on how to act in this new context.

Our analysis has focused on dairy farmers in Brittany (France). It is unclear whether similar findings would apply to other EU regions. As suggested by Bouamra-Mechemache et al. (2008), the effect of the quota removal on investment behavior and production could differ across countries. Without quotas, we may see major adjustments in EU milk production toward the regions having a comparative advantage in producing milk. This shift could happen both within the EU as well as outside the EU. The net effects will determine the evolving position of European milk producers in the global market. The role of efficiency and the productive capacity of farmers will be very crucial in this competition.

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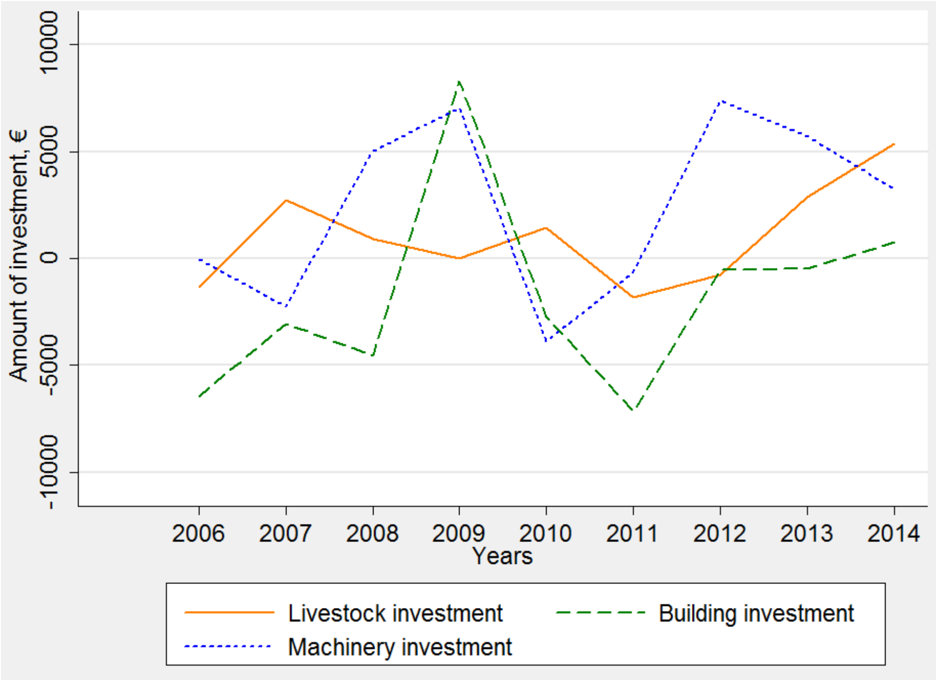
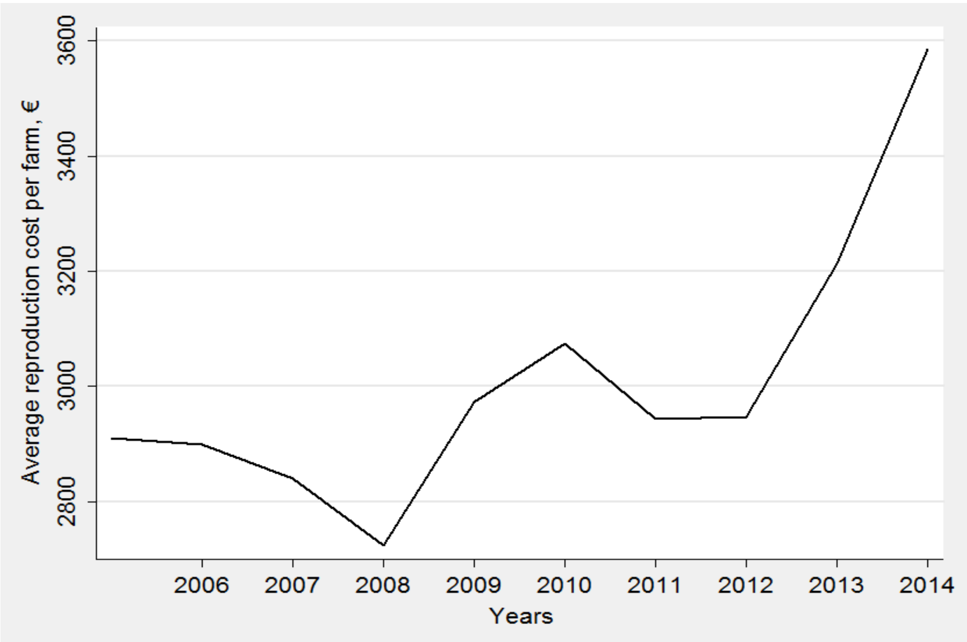
Appendices

FIGURE 2.3: Evolution of the average investment (machinery, building and livestock) over the period 2005-2014 in our sample.



Source: The authors, based on CER FRANCE Ille-et-Vilaine.

FIGURE 2.4: Evolution of the average reproduction cost per farm over the period 2005-2014 in our sample.



Source: The authors, based on CER FRANCE Ille-et-Vilaine.

CHAPTER 3.

Farm performance and investment decisions: evidence from the French (Brittany) dairy sector[11]

Abstract

The objective of this paper is to investigate the role of farm performance in investment decisions by estimating an adjustment cost model on a balanced sample of specialised dairy farms in Brittany (western France) between 2005 and 2014. Two farm types are considered, those with high and those with low capital intensity. The results show that spreading investment over time is, on average, an optimal strategy for maintaining performance in the presence of adjustment costs. In addition, the effect of performance on investment behaviour differs between the two farm types.

3.1 Introduction

Investment helps farmers remain competitive by adapting to changing conditions such as higher price volatility and policy changes. In recent decades, trade liberalisation and reforms of the European Union's (EU) Common Agricultural Policy (CAP), particularly the 2003 Luxembourg agreement, which replaced most of the coupled payments with the decoupled Single Farm Payment (SFP), have resulted in both higher uncertainties for farmers and higher price volatility. In the case of dairy farms, one recent major policy change was the ending of milk quotas. Quotas were fully removed in 2015, but the reform had been announced as early

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as 2003 and further confirmed in 2008, with a range of measures aimed at achieving a "soft landing". These measures consisted in increasing dairy quotas progressively by 2% in 2008/2009 and 1% per year until 2015. In such context, dairy farmers may have increased their assets through investment as early as 2008, so as to be ready as soon as quotas were fully removed in 2015.

The determinants of firms' investment behaviour have been largely studied in the economic literature. Economic determinants have been the most studied, namely the output price, the capital price and the output quantity sold and, by extension, the output quantity produced (Chirinko, 1993), followed by financial determinants, namely financial constraints and interest rates (Budina et al., 2000; Latruffe, 2005; O'Toole et al., 2014). Besides economic and financial determinants, other determinants investigated include public policy (Sckokai and Moro, 2009; Bojnec and Latruffe, 2013), quasi-fixity of assets, irreversibility of investment, sunk costs and adjustment costs (Bokusheva et al., 2009; Chavas, 1994; Oude Lansink and Stefanou, 1997). The adjustment cost theory assumes that farms experience adjustment costs when they invest, such as the cost of extra labour time or production losses, until both farmer and herd become familiar with new machines and technologies. Bokusheva et al. (2009) showed that the adjustment cost model is adequate for evaluating investment behaviour in the farming sector mainly in the short term. The fixity and the specificity of assets make the adjustment cost approach very relevant in the agricultural sector.

However, the literature on adjustment costs usually excludes from the analysis the role played by organisational factors such as managerial performance. In theory, the impact of farm performance on investment is ambiguous, and there is no empirical evidence on the role of organisational drivers and performance on investment. On the one hand, high farm performance (for instance better productivity inducing better income) can allow farmers to afford investment in the future, in line with the accelerator effect; on the other hand, farmers with a highly performing farm may postpone investment in order to avoid adjustment costs that would decrease their performance in the short term. This implies that, despite external signals that are supposed to trigger investment (e.g. milk quotas removal), we may not see this in reality, or, at least, not for all farms. This may depend on farm initial performance level, but also on their initial capital endowment.

In this context, the objective of this article is to investigate the effect of current performance on future investment decisions, for the particular case of the dairy sector, accounting for heterogeneity through different farm capital intensities. For this, we consider two groups of farms with different initial capital intensity: farms that have a high capital intensity, and farms that have a low capital intensity. Our analysis is applied to a sample of specialised dairy farms in a French western region in Brittany, staying in business all along the 2005-2014 period. There is an important break in this period, namely the year 2008 when the end of milk quotas was announced. Between 2005 and 2008 the dairy sector was supported by milk quotas. Then, between 2008 and 2014 the upper limitation to produce was progressively increased, and farms might have implemented higher investments to prepare themselves for the full quota removal in 2015.

The article is structured as follows. Section 2 develops the underlying theoretical framework that guides the econometric estimations. Section 3 describes the database and explains the econometric specification. Section 4 presents the results while Section 5 concludes.

3.2 Theoretical framework

In this section, we develop a simple theoretical framework that will guide our empirical estimations. Based on the neoclassical theory of optimal capital accumulation (Hall and Jorgenson, 1967), our model assumes an intertemporal maximisation of profit with adjustment costs. Contrary to the ad hoc accelerator model, an adjustment cost model can provide a consistent theoretical basis for explaining agricultural investment patterns in the context of dynamically optimising economic agents. Adjustment cost theory has been the main approach used in the literature on investment to explain why firms partially adapt their capital stock to the optimal level (Bond and Meghir, 1994; Hubbard and Kashyap, 1992; Lizal and Svejnar, 2002; Rizov, 2004). According to this theory, firms undergo a short-run loss in output or profit when they modify their stocks of quasi-fixed production factors due to adjustment costs. These costs arise from actions aimed at adjusting the firm to new operating conditions (Caballero, 1999). Such adjustment costs are relevant in the agricultural sector due to the existence of asset fixity, especially in the livestock sector (e.g., as argued by Galbraith and Black, 1938). In the firms' profit maximising framework, the adjustment cost hypothesis is formalised by including adjustment costs explicitly as an argument in the profit function.

To keep the model simple, we assume that dairy farmers are risk neutral and have rational expectations. In this case, the framework consists of a maximisation of the expected net present value of the farmer's profits in period *t* over an infinite horizon:

$$\text{Max } E_{it} \left\{ \sum_{t=0}^{\infty} \frac{1}{(1+r_t)} \pi_{it}\{K_{it}, I_{it}, X_{it}\} \right\} \tag{1}$$

on K_{it}, I_{it}, X_{it}

subject to

$$K_{it} = (1-\delta)K_{it-1} + I_{it} \tag{2}$$

$$\pi_{it}\{K_{it}, I_{it}, X_{it}\} \geq 0 \tag{3}$$

where subscript *i* refers to the *i*-th farm and subscript *t* refers to the *t*-th period; π_{it} is the farm profit; farm capital K_{it} is a stock variable and investment I_{it} is a flow variable; X_{it} is the level of variable inputs used on the farm; r_t is the interest rate; δ is the depreciation rate; E_{it} is the expectation operator conditional on information available to the *i*-th farmer at the start of period *t*, expectations being taken over future prices and technologies (Bond and Meghir, 1994).

Equation (2) represents capital accumulation, in the sense that the current capital stock consists of last year's capital stock without capital that has depreciated at rate δ, plus current investment. Equation (3) is a non-negativity constraint that ensures that the farm profit is positive in each period. The Euler equation defining the optimal investment path can then be derived:

$$E_{it}\left\{\frac{\partial \pi_{it}}{\partial I_{it}}\right\} - (1-\delta)\frac{1}{(1+r_t)} E_{it}\left\{\frac{\partial \pi_{it+1}}{\partial I_{it+1}}\right\} + E_{it}\left\{\frac{\partial \pi_{it}}{\partial K_{it}}\right\} = \varepsilon_{it+1} \tag{4}$$

where ε_{it+1} is an error term capturing rational expectations (Muth, 1961). It implies that the expected value in period *t*-1 is equal to the value in period *t* corrected with an error term, and assumed to be uncorrelated with the explanatory variables.

For the i-th farm in period t, the profit is specified as:

$$\pi_{it} = p_{it}\, y_{it} - w_{it}\, X_{it} - q_{it}\, I_{it} - p_{it}\, C_{it} \tag{5}$$

where $p_{it} \in \mathbb{R}_+$ is the price of agricultural output y_{it}; $w_{it} \in \mathbb{R}_+^m$ are the prices of the variable inputs X_{it}; $q_{it} \in \mathbb{R}_+$ is the price of investment I_{it}; and C_{it} is adjustment costs.

The production function for the agricultural output is specified as Cobb-Douglas:

$$y_{it} = {K_{it}}^{\alpha} {X_{it}}^{1-\alpha} \tag{6}$$

where α is the elasticity of output with respect to capital such that $0 < \alpha < 1$.

Following Gardebroek and Oude Lansink (2004) and Benjamin and Phimister (2002), adjustment costs are assumed to be increasing and convex, and can be specified as a quadratic function of the investment to capital ratio:

$$C_{it} = \frac{b}{2}\left(\frac{I_{it}}{K_{it}} - d\right)^2 K_{it} \tag{7}$$

where *b* and *d* are parameters such that *b*>0 and *d*>0.

The first-order necessary conditions for the choice of capital K_{it} and investment I_{it} are:

$$\frac{\partial y_{it}}{\partial K_{it}} = \alpha \frac{y_{it}}{K_{it}} \tag{8a}$$

$$\frac{\partial C_{it}}{\partial K_{it}} = \frac{b}{2}\left[-\left(\frac{I_{it}}{K_{it}}\right)^2 + d^2\right] \tag{8b}$$

$$\frac{\partial C_{it}}{\partial I_{it}} = b\left(\frac{I_{it}}{K_{it}} - d\right) \tag{8c}$$

Combining equation (4) with equations (8a), (8b) and (8c), we obtain the following Euler equation with full specifications:

$$p_{it}\alpha\frac{y_{it}}{K_{it}} + p_{it}\frac{b}{2}\left(\frac{I_{it}}{K_{it}}\right)^2 + p_{it}bd - p_{it}\frac{b}{2}d^2 + (-bd)\,(1-\delta)\frac{1}{(l+r_t)}p_{it+1} +$$
$$(1-\delta)\frac{1}{(l+r_t)}b\frac{I_{it+1}}{K_{it+1}}p_{it+1} + (1-\delta)\frac{1}{(l+r_t)}q_{it+1} - p_{it}b\frac{I_{it}}{K_{it}} - q_{it} = \varepsilon_{it+1} \tag{9}$$

Assuming that the output price, the interest rate and the price of investment are constant through time and across farms (as for example in Bond and Meghir, 1994, and Benjamin and Phimister, 1997), equation (9) can be rewritten as:

$$\frac{I_{it+1}}{K_{it+1}} = \beta_0 + \beta_1\left(\frac{y_{it}}{K_{it}}\right) + \beta_2\left(\frac{I_{it}}{K_{it}}\right) + \beta_3\left(\frac{I_{it}}{K_{it}}\right)^2 + \varepsilon_{it+1} \tag{10}$$

where

$$\beta_0 = \frac{p_{it}}{p_{it+1}}\frac{(l+r_t)}{(1-\delta)}d(d-b) + d + \frac{1}{b}\frac{q_{it}\frac{(l+r_t)}{(1-\delta)} - p_{it+1}}{p_{it+1}} \quad (11)$$

$$\beta_1 = -\frac{p_{it}}{p_{it+1}}\frac{(l+r_t)}{(1-\delta)}\frac{\alpha}{b} \quad (12)$$

$$\beta_2 = \frac{p_{it}}{p_{it+1}}\frac{(l+r_t)}{(1-\delta)} \quad (13)$$

$$\beta_3 = -\frac{p_{it}}{p_{it+1}}\frac{1}{2}\frac{(l+r_t)}{(1-\delta)} \quad (14)$$

Equation (13) shows that the coefficient on the lagged investment ratio (β_2) is expected to be positive, indicating that farmers tend to smooth their investment over time in order to keep adjustment costs low. Equation (12) shows that the coefficient of the output term (β_1) is expected to be negative, indicating that when the productivity of capital is high, investment will be postponed in later periods than the next period (i.e. in *t*+2 or later) in order to keep adjustment costs low. Finally equation (14) shows that the coefficient of the squared lagged investment ratio (β_3), representing the marginal cost of having a higher level of capital in the profit function, is expected to be negative.

3.3 Data and econometric specification

The data includes accountancy information for a fully balanced sample of 620 dairy farms in one sub-region of Brittany (called Ille-et-Vilaine), provided by a regional private accounting office,[12] covering the 2005-2014 period. Hence, the pooled ten years sample includes 6,200 observations.

Capital (K_t) is proxied by the net value of fixed assets, including buildings and machinery. Investment (I_t) is net investment computed as the difference between capital in period *t* and capital in period *t*-1.[13] The output (y_t) is measured by the amount of milk sales. To proxy managerial performance, we use four different indicators: (i) milk gross margin per 1,000 litres of milk; (ii) farm operational expenses, that is to say costs related to the farming operations (including costs for purchased animal feed, produced forage, straw litter, and fuel; veterinary and animal reproduction costs; costs of temporary labour) per 1,000 litres of milk;

[12] CER FRANCE Ille-et-Vilaine. This accounting office manages the accounts of the majority of farmers in Brittany.

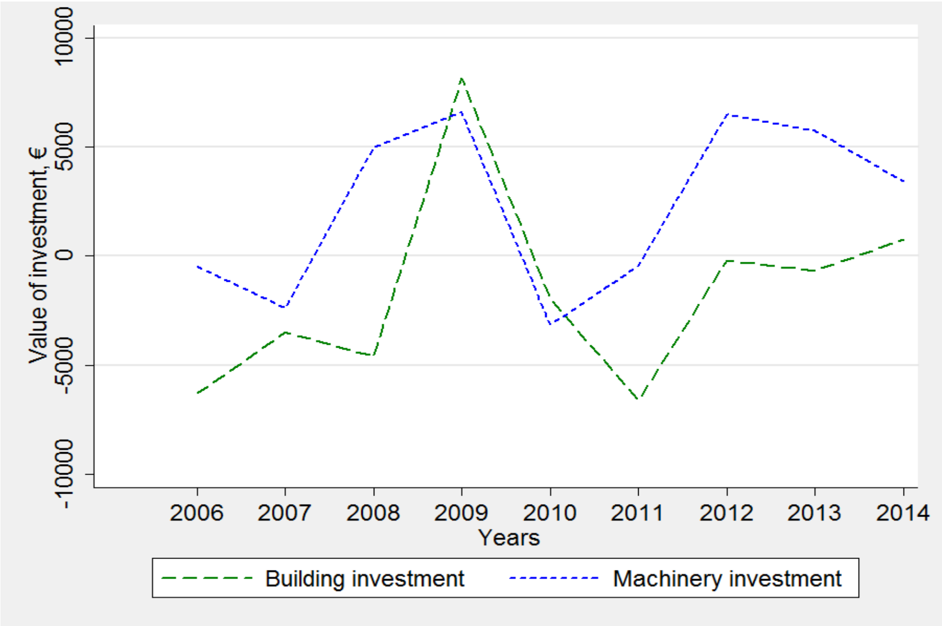
[13] Values of capital and investment in period *t* were deflated by the price index of investment goods with base year 2010.

(iii) volume (in litres) of milk produced per dairy cow; and (iv) farm margin rate, that is to say milk gross margin divided by milk production. Higher milk gross margin, volume of milk produced and farm margin rate mean higher farm performance. By contrast, lower farm operational expenses mean higher farm performance, as it shows that the farm can better manage its costs.

As shown in Table 3.1, during the period considered, farms in the sample operated on average 73 hectares (ha) of utilised agricultural area (UAA), used 1.9 full-time equivalent labour units, and bred 51 dairy cows, producing 7,108 litres of milk per cow. Table 3.1 also shows that farms in our sample have a higher milk yield and are larger on average than those from the exhaustive Agricultural Census population of the same sub-region in terms of UAA and labour use, but almost similar in terms of number of cows.

Figure 3.1 displays, for our sample, the evolution of the yearly average level of investment over the period considered. It shows that the evolution is up-and-down, with ups in 2009 and 2012

FIGURE 3.1: Evolution of the average investment over the period 2005-2014 in the sample used



Source: The authors, based on CER FRANCE Ille-et-Vilaine

TABLE 3.1: Descriptive statistics of the sample used and comparison with the Agricultural Census population

	Sample used (Sample's average over 2005-2014)	Total farm population in the same sub-region as our sample (Population's average in 2010; Agricultural Census)
Milk produced (litres)	365,127	356,110
UAA (ha)	73	63
Number of dairy cows	51	52
Number of full-time labour equivalent units	1.9	1.7
Milk yield (litres / cow)	7,108	7,036
Number of observations	620	3,248

Source: The authors, based on CER FRANCE Ille-et-Vilaine and Agreste (2010)

Based on the theoretical model of equation (9), our baseline empirical specification is as follows:

$$\frac{I_{it+1}}{K_{it+1}} = \beta_0 + \beta_1\left(\frac{y_{it}}{K_{it}}\right) + \beta_2\left(\frac{I_{it}}{K_{it}}\right) + \beta_3\left(\frac{I_{it}}{K_{it}}\right)^2 + \beta_4\text{age}_{it} + \beta_5\text{Dummy2008}_t + \beta_6\text{performance}_{it} + \varepsilon_{it+1} \qquad (15)$$

where subscript *i* refers to the *i*-th farm and subscript *t* refers to the *t*-th period; β_0 to β_6 are the parameters to be estimated; $\varepsilon_{i,t+1} = s_i + w_{i,t}$ is the disturbance containing farm-specific effects s_i and random noise w_{it}; age_{it} is the farmer's age in years and is used as a control variable for farmer's life cycle; Dummy2008_t is a dummy variable taking the value one if the year is 2008, and zero if not, and is used as a control variable for two important events of 2008, namely the announcement of the end of the milk quotas and the large increase in milk price; performance_{it} is the performance proxy.

We employ the generalised method of moments (GMM) (Arellano and Bond, 1991; Arellano and Bover, 1995) as it allows account for two sources of potential endogeneity: correlation between explanatory variables and the error term, which can be due to unobserved heterogeneity such as soil conditions; correlation between the performance variable and the investment variable. We use internal instruments, lagged over two periods (Barran and Peeters, 1998; Bond and Meghir, 1994; Rizov, 2004). We estimate the model in first differences (Bokusheva et al., 2009; O'Toole et al., 2014) to eliminate the farm-specific effect s_i from the investment equation.

TABLE 3.2: Descriptive statistics of the main variables of interest for the sample used

	Mean	Std. Dev	Min	Max	Number of observations
Variables used in the estimation					
$\frac{y_{it}}{K_{it}}$	0.681	0.301	0.088	3.251	6,200
$\frac{I_{it}}{K_{it}}$	-0.008	0.158	-1.367	0.852	5,580
$\left(\frac{I_{it}}{K_{it}}\right)^2$	0.251	0.054	4.49e-10	1.869	5,580
age_{it}	41.9	8.9	15	67	6,200
Dummy2008_t	0.1	0.30	0	1	6,200
Farm milk gross margin per 1,000 litres of milk	241.5	62.3	-34.4	651.3	6,200
Farm operational expenses per 1,000 litres of milk	652.8	394.3	47.0	6,461.8	6,200
Volume of milk produced per dairy cow	7,108	1,289	700	11,093	6,200
Farm margin rate	0.75	0.14	-0.11	1.9	6,200
Variables in levels					
Investment (I_t) (€)	2,912	51,598	-333,685	1,467,339	5,580
Capital (K_t) (€)	241,185	129,963	23,411	1,943,785	6,200

Source: The authors, based on CER FRANCE Ille-et-Vilaine

Table 3.2 provides summary statistics for the variables included in the model as well as investment and capital in levels. On average, the level of investment over the period is €2,912 per farm in our sample. The standard deviation is high, indicating large heterogeneity in investment behaviour across farms and years. Over the period considered, the annual percentage of zero and negative investment values is, on average, 55 percent (i.e. 45 percent of positive investment values) which explains why the mean investment is low and the mean value of investment to capital ratio $\left(\frac{I_{it}}{K_{it}}\right)$ is close to zero (namely -0.008). All four performance variables show a relatively high standard deviation revealing high heterogeneity in the technology.

Table 3.2 reveals heterogeneous technologies within the sample, notably in terms of capital and variable inputs (operational expenses). Such technological heterogeneity may imply different adjustment costs, and hence different investment strategies and different impact of performance on investment decisions. For this reason, equation (15) is estimated twice: once as it is specified in equation (15) and on the whole sample; and once, also on the whole sample but with interaction effects, that is to say with each explanatory variable interacted with a dummy variable capturing the farms' capital intensity. Using Hierarchical Ascendant Classification (HAC) with Ward's method, a cluster analysis is performed in order to identify groups of farms, where groups differ in terms of capital intensity. The following specific characteristics are considered to separate farms into groups: the herd size in terms of number of dairy cows; the share of fodder maize in the farm forage area; the stocking rate in terms of livestock units (LU)[14] per ha; the cost of work outsourcing per LU; the cost of concentrates per dairy cow; and the capital per LU. In the HAC, we wish to identify the groups not only according to their average capital intensity during the full period, but also to the evolution of their capital intensity over the period. For this, we use two types of variables in the HAC: static ones, namely the average value over the whole period 2005-2014 for each characteristic listed above; and dynamic ones, namely the rate of growth of each characteristic between 2005 to 2014.

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The HAC identifies two farm clusters. For both clusters, Table 3.3 reports descriptive statistics of the variables used for the classification. On average, compared to farms in cluster 2 (226 farms), farms in cluster 1 (394 farms) exhibit significantly larger size in terms of number of dairy cows (53 vs. 47), have a higher share of fodder maize in forage area (42 vs. 33 percent), a higher stocking rate (1.67 vs 1.62 LU/ha), higher concentrates expenses per dairy cow (€395 vs. 224), and costs of work outsourcing per LU (€1.89 vs. 1.27). Likewise, farms in cluster 1 experienced a higher rate of growth in the number of dairy cows (0.34 vs. 0.22) and stocking rate (0.06 vs. 0.01) between 2005 and 2014. This suggests that, on average, farms in cluster 1 are more capital intensive than farms in cluster 2. Thus, in what follows farms in cluster 1 are called farms with "high capital intensity" (HCI), while farms in cluster 2 are called farms with "low capital intensity" (LCI).

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[14] Livestock units (LU) allow the aggregation of the number of livestock heads from different types of animals, here dairy heifers, calves and dairy cows. Each type of animal is assigned a coefficient depending on its feed consumption.

TABLE 3.3: Descriptive statistics of the variables used in the hierarchical ascendant classification analysis for the two clusters identified

	Cluster 1 High capital intensive (HCI) farms (394 farms)	Cluster 2 Low capital intensive farms (LCI) (226 farms)	t-test (equality of means)
Average over 2005-2014 (*standard deviation*)			
Number of dairy cows	53 (*18*)	47 (*16*)	***
Share of fodder maize in forage area (percent)	42 (*11*)	33 (11)	***
Stocking rate (LU/ha)	1.67 (*0.35*)	1.62 (*0.31*)	***
Cost of work outsourcing per LU (€)	1.89 (*0.78*)	1.27 (*0.59*)	***
Concentrates cost per dairy cow (€)	395 (*217*)	224 (*84*)	**
Capital stock per LU (€)	76 (*33*)	62 (*23*)	***
Rate of growth between 2005 and 2014 (*standard deviation*)			
Number of dairy cows	0.34 (*0.31*)	0.22 (*0.23*)	***
Share of fodder maize in forage area	-0.13 (*1.03*)	-0.23 (*0.50*)	**
Stocking rate	0.06 (*0.19*)	0.01 (*0.15*)	***
Concentrates cost per dairy cow	0.67 (*0.84*)	0.68 (*0.84*)	***
Capital stock per LU	0.21 (*0.38*)	0.24 (*0.35*)	

Notes: The rate of growth is computed as the difference between the value in 2014 and the value in 2005, divided by the value in 2005. The rate of growth of the cost of work outsourcing per LU was not used in the HAC because it is correlated with other variables., **, ***: significance at the 10, 5, 1 percent level.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

3.4 Results

3.4.1 Estimation results for the full sample

Table 3.4 shows the results of the estimation of the investment model in equation (15) for the full sample, without and with each of the four different performance indicators. Results indicate that the model is highly significant each time, as shown by the Wald tests.

Three main findings can be observed in Table 3.4. Firstly, the coefficient for the investment to capital in period *t* is significant and positive, while the coefficient for the square of investment to capital in period *t* is significant and negative. This indicates that higher (lower) investment in period *t* increases (decreases) investment in period *t+1*. This is consistent with the underlying theoretical framework and suggesting that farmers smooth their investment over time in order to undergo the lowest adjustment costs. These adjustment costs are captured by the negative value of β_3, showing the marginal cost of having a higher level of capital in the profit function. All this reveals that the adjustment cost model is an adequate framework for our sample. Secondly, the coefficient for the farm milk gross margin per 1,000 litres of milk is negative and significant. This reveals that, on average for the full sample, the higher the performance, the less farms invest. This is again consistent with the adjustment cost theory suggesting that a farm will not invest in the short term if its performance is currently high so as to undergo fewer possible adjustment costs. The same finding holds when the farm margin rate is used as the performance indicator (table 3.4). By contrast, the coefficients related respectively to the farm operational expenses per 1,000 litres of milk and the volume of milk produced per dairy cow are not significant.

Thirdly, the coefficient for the ratio of output to capital in period *t* is significant and positive, which is not the expected sign from the theoretical model. This result has also been found by Rizov (2004) for Romanian manufacturing firms over the period 1995-1999. The author suggests that this reveals that adjustment costs are not an issue in the case studied. However, as said above, adjustment costs are non-negligible in the dairy sector as shown by Oude Lansink (1997). One explanation for our sample is the business taxation system in France, which encourages farmers to invest in order to reduce their tax base and hence to reduce their corporation tax burden and social contributions.

Regarding the control variables, farmer's age has a significant impact in the investment model with performance, when we use farm milk gross margin per 1,000 litres of milk as performance variable. The impact is negative, indicating that older farmers invest less. As for the dummy variable capturing the year 2008, it has a significantly positive impact on investment, as expected: the prospect of milk quotas removal as well as high milk prices increased farm investment compared to the other years of the period.

Finally, results indicate that the model specification is strongly rejected, in terms of the Sargan test criterion, as the p-value is less than 10 percent. This may be due to heterogeneity in the sample, which we next account for.

TABLE 3.4 : Results of the estimation of the investment model (equation (15)) for the whole sample: estimated coefficients

	Dependent variable: investment per capital in *t*+1				
	Investment model without the performance variable	Investment model with a performance variable			
	(1)	(2)	(3)	(4)	(5)
$\frac{y_{it}}{K_{it}}$	0.11783***	0.12147***	0.11799***	0.11771***	0.11900***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
$\frac{I_{it}}{K_{it}}$	0.06089***	0.06609***	0.06112***	0.06134***	0.06216***
	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
$\left(\frac{I_{it}}{K_{it}}\right)^2$	-0.07353**	-0.08031***	-0.07439**	-0.07339**	-0.07760***
	(0.029)	(0.030)	(0.029)	(0.029)	(0.029)
age_{it}	0.00216	-0.00522*	0.00162	0.00191	-0.00221
	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)
Dummy2008_t	0.06139***	0.06747***	0.06366***	0.05975***	0.06446***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Farm milk gross margin per 1,000 litres of milk_{it}		-0.00048***			
		(0.000)			
Farm operational expenses per 1,000 litres of milk_{it}			0.00003		
			(0.000)		
Volume of milk produced per cow_{it}				0.00001	
				(0.000)	
Farm margin rate_{it}					-0.13934**
					(0.061)
Constant	-0.29326***	0.11912	-0.29013***	-0.31829***	-0.00911
	(0.089)	(0.144)	(0.089)	(0.102)	(0.152)
Number of observations	4,340	4,340	4,340	4,340	4,340
Number of farms	620	620	620	620	620
Wald Chi2	149.21***	148.68***	149.15***	151.27***	150.64***
Sargan test: p-value	0.0130	0.0162	0.0129	0.0136	0.0131
Instruments: lagged variables in period	*t*-2	*t*-2	*t*-2	*t*-2	*t*-2

*Notes: Robust standard errors in parentheses. *, **, ***: significance at the 10, 5, 1 percent level.* *Source: The authors, based on CER FRANCE Ille-et-Vilaine*

3.4.2 Estimation results when farms are separated in two capital intensity groups

As explained above we separated the farms into two groups based on their capital intensity. To investigate whether both groups have a different strategy in terms of investment, we estimate again our investment model (equation 15) but this time as an interaction model on the full sample. More precisely, we interact all explanatory variables with a dummy variable, $\mathtt{DummyHCI}_i$, taking the value one for farms with HCI and zero for farms with LCI.

Table 3.5 reports the results of the estimation of this interaction investment model where the reference group is LCI. Hence, the coefficients for this reference group are those for the variables without interaction with $\mathtt{DummyHCI}_i$, while coefficients for the HCI farms are obtained by adding the coefficients for the reference group and the coefficients for the variables interacted with $\mathtt{DummyHCI}_i$. For example, in the investment model without performance (column (1)), the coefficient for the investment to capital ratio in period *t* is 0.65190 for LCI farms, while the coefficient for HCI farms is obtained by adding 0.65190 and -1.00289 which gives the value -0.35099.

Three main findings can be noted. Firstly, the coefficient for the square of investment to capital in period *t* is non-significant but the coefficient for the investment to capital in period *t* is (significant and) positive for LCI farms, suggesting that these farms undergo adjustment costs which encourage them to smooth their investment over time. However, contrary to the expectation, the coefficient for the investment to capital in period *t* is (significant and) negative for HCI farms, revealing that these farms decrease their investment in period *t*+1 when they have already implemented high investment in period *t*. One explanation of this difference between HCI and LCI farms can be found in the difference of borrowing capacity. Table 3.6 shows that the level of debt ratio is higher for HCI farms than LCI farms, meaning that LCI farms have higher borrowing capacity and hence higher investment capacity than HCI farms.

Secondly, the coefficient for performance proxied by farm milk gross margin per 1,000 litres of milk (column (2)) is significant and negative for both groups of farms (Table 5). This finding is similar to the case of the full sample (Table 3.4) and suggests that both groups of farms face the above-mentioned trade-off between investing now or delaying investment in a view of avoiding a decrease in performance in the following year due to adjustment costs. The same finding is shown for two other performance indicators, namely farm margin rate (negative sign of the coefficient; column (5)) and farm operational expenses per 1,000 litres of milk (positive sign of the coefficient; column (3)). Moreover, the magnitude of the impact of performance is higher for LCI farms than for HCI farms whatever the performance indicator, revealing that the trade-off is stronger for LCI farms. However, performance proxied by the volume of milk produced per farm has a positive effect on investment for both groups of farms, although it is stronger for LCI than for HCI (column (4)). This is similar to the effect found for the output to capital ratio.

Indeed, thirdly, the coefficient for the output to capital ratio in period *t* is significant and positive for both groups of farms, confirming the unexpected effect observed for the full sample (Table 3.4). The magnitude of this effect is higher for LCI farms than for HCI farms revealing that LCI farms invest more when output to capital in period *t* is higher. This, again, may be linked to higher borrowing capacity of LCI farms (Table 3.6). It may also reveal a stronger tax strategy for LCI farms.

As regards the control variables, the negative impact of age is confirmed for LCI in the case where farm milk gross margin per 1,000 litres of milk is used as performance (column (2)). By contrast, the effect is positive for HCI in the cases where farm milk gross margin per 1,000 litres of milk and farm margin rate are used as performance (columns (2) and (5)), indicating that in this group of farms, older farmers invest more. The dummy capturing the economic conditions of year 2008 has the same positive impact on the investment behaviour of both groups of farms.

Finally, the Sargan test of over-identifying restrictions does not reject the null hypothesis of the validity of instruments at the 10 percent level of significance. This result confirms that there is heterogeneity in terms of capital intensity in our sample, and this specification with interaction dummy has succeeded to control for such differences.

TABLE 3. 5 : Results of the estimation of the investment interaction model for the whole sample: estimated coefficients

	Dependent variable: investment per capital in *t*+1				
	Investment model without the performance variable	Investment model with a performance variable			
	(1)	(2)	(3)	(4)	(5)
$\frac{y_{it}}{K_{it}}$	0.14104***	0.14911***	0.14399***	0.14116***	0.14179***
	(0.020)	(0.021)	(0.020)	(0.020)	(0.020)
$\frac{y_{it}}{K_{it}} \times$ DummyHCI$_i$	-0.02465	-0.03042	-0.02764	-0.02495	-0.02358
	(0.021)	(0.022)	(0.021)	(0.021)	(0.021)
$\frac{I_{it}}{K_{it}}$	0.65190***	0.64880***	0.64706***	0.65329***	0.64722***
	(0.080)	(0.084)	(0.082)	(0.081)	(0.083)
$\frac{I_{it}}{K_{it}} \times$ DummyHCI$_i$	-1.00289***	-0.99496***	-0.99708***	-1.00443***	-0.99447***
	(0.085)	(0.088)	(0.087)	(0.086)	(0.088)
$\left(\frac{I_{it}}{K_{it}}\right)^2$	0.02119	0.05399	0.05085	0.01895	0.04646
	(0.104)	(0.114)	(0.111)	(0.105)	(0.111)
$\left(\frac{I_{it}}{K_{it}}\right)^2 \times$ DummyHCI$_i$	-0.04431	-0.08158	-0.07408	-0.04156	-0.07335
	(0.109)	(0.119)	(0.116)	(0.110)	(0.117)
age$_{it}$	0.00473	-0.01838***	-0.00207	0.00455	-0.00973
	(0.004)	(0.006)	(0.004)	(0.004)	(0.006)
age$_{it}$ × DummyHCI$_i$	0.00099	0.02117***	0.00797	0.00104	0.01271*
	(0.005)	(0.007)	(0.005)	(0.005)	(0.007)
Dummy2008$_t$	0.07758***	0.09163***	0.10034***	0.07643**	0.08394***
	(0.030)	(0.030)	(0.030)	(0.031)	(0.030)
Dummy2008$_t$ × DummyHCI$_i$	-0.02962	-0.04053	-0.05238	-0.02948	-0.03371
	(0.031)	(0.032)	(0.032)	(0.033)	(0.031)
Farm milk gross margin per 1,000 litres of milk$_{it}$		-0.00143***			
		(0.000)			
Farm milk gross margin per 1,000 litres of milk$_{it}$ × DummyHCI$_i$		0.00122***			
		(0.000)			
Farm operational expenses per 1,000 litres of milk$_{it}$			0.00038***		
			(0.000)		
Farm operating expenses per 1,000 litres of milk$_{it}$ × DummyHCI$_i$			-0.00038***		
			(0.000)		
Volume of milk produced per cow$_{it}$				0.000003***	
				(0.000)	
Volume of milk produced per cow$_{it}$ × DummyHCI$_i$				-0.0000007*	
				(0.000)	

Farm margin rate$_{it}$					-0.46180***
					(0.138)
Farm margin rate$_{it}$ × DummyHCI$_i$					0.37402**
					(0.149)
Constant	-0.44838***	0.15199	-0.42714***	-0.46468***	0.02696
	(0.100)	(0.155)	(0.100)	(0.112)	(0.164)
Number of observations	4,340	4,340	4,340	4,340	4,340
Wald Chi2	1211.02***	1240.40***	1231.77***	1217.33***	1204.90***
Sargan test: p-value	0.1228	0.1911	0.1608	0.1232	0.1753
Instruments: lagged variables in period	*t*-2	*t*-2	*t*-2	*t*-2	*t*-2

*Notes: *, **, ***: significance at the 10, 5, 1 percent level.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

TABLE 3. 6: Comparison of debt ratio for HCI farms and LCI farms

	Number of observations	Mean	Std.Dev	Min	Max
		LCI farms			
Debt ratio	2,260	43.6	20.6	0.64	148.7
		HCI farms			
Debt ratio	3,940	52.1	19.9	2.4	142.3

Source: The authors, based on CER FRANCE Ille-et-Vilaine

3.5 Conclusion

This article provides a new perspective on investment decisions in the dairy farm sector by taking into account (i) the link between farm investment and farm performance, and (ii) farmers' differing investment strategies depending on the level of their initial farm capital intensity. For this, the effect of current farm performance on future investment decisions is investigated using an adjustment cost framework and including farm performance in the empirical model estimated with GMM. The model is estimated for the full sample without and with interaction terms that capture two groups of farms identified with HAC: high capital intensive farms (HCI), and low capital intensive farms (LCI). The application is to the dairy sector in a sub-region of Brittany (western France) for the 2005-2014 period.

Firstly, results show that smoothing farm investment over time is, on average for the full sample, an optimal strategy in the presence of adjustment costs, as for example reported by Gardebroek and Oude Lansink (2004). Secondly, the influence of performance on farm investment is negative, revealing farmers' trade-off between investing now to increase their farm size and their performance, or postponing investment in order to avoid a decrease in performance in the following year due to adjustment costs. The magnitude of this effect is higher for LCI farms. Thirdly, on average, the coefficient for the output to capital ratio in period t is significant and positive for both groups of farms. This goes against the theory of adjustment costs, but may reveal a specificity of the French agricultural sector. During the period studied, the French business taxation system provided incentives to farmers to invest in order to reduce their tax and social contributions. The magnitude of this effect is higher for LCI farms than for HCI farms, suggesting that a reduction in tax matters more for LCI farms than for HCI farms. This may also reveal a standardisation trend in terms of technology (or catching-up) in this specialised dairy region.

Finally, our findings highlight that farmers' heterogeneity needs to be accounted for in modelling investment behaviour. From a methodological point of view, the interaction model was found to be well specified, contrary to the model without interacting variables with the group dummy. From a policy point of view, accounting for heterogeneity allows differentiated strategies to be revealed and can help design targeted policies aimed at encouraging investment, in particular in the context of quota system removal.

We should note here some limitations to our analysis. Our objective was to investigate how performance was linked to farms' investment decisions, and in order to limit the complexity of the modelling framework and the econometric estimations, we deliberately made some simplifying assumptions. Firstly, we assumed that farmers' were risk neutral, although some literature has shown that some farmers are risk averse (Liu, 2013; Young, 1979). Introducing risk in the modelling strategy is hence one avenue for future research. Secondly, we modelled rational expectations but the literature on investment has highlighted that farmers may have other types of expectations (Thijssen, 1996; Chavas, 1999). This may be the case in the context of an increased milk price volatility, which occurred during our studied period, notably with an important spike between 2008 and 2010. Modelling risk behaviour and different expectations is a challenging exercise, as shown for example by Femenia et al. (2017), but may help disentangle price effects from adjustment costs effects in the coefficient of the output to capital ratio.

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CHAPTER 4.

Spatial effects in investment decisions: Evidence from French dairy farms[15]

Abstract

This article analyses the spatial effects in farmers' investment decisions, in particular the role of neighbourhood effects, for the specific case of dairy farmers in a region of Western France. Investment decisions are measured by investment spikes, enabling the analysis to be linked to the literature on adoption of technology innovation. The main contribution is in accounting for the effect of the previous decisions of the farmers' neighbours, with the help of a spatial probit econometric model that includes investment age. Results show that farmers are not immediately influenced by the simultaneously-made decisions of their neighbours, but rather by the decisions taken by their neighbours in the year before. However, this positive influence does not compensate for the negative effect of own previous investment decisions.

4.1 Introduction

The end of the European Union's (EU) dairy quota policy was confirmed in 2008 with milk quotas gradually increasing up to their abolition on 31 March, 2015. This change in agricultural policy may trigger substantial investment decisions by farmers in order to increase their production capacity through expansion or modernisation. From a policy perspective, understanding the determinants of farm investment in a changing policy and

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economic context can help draw policy recommendations on how best to support farmers throughout the changes.

In the economic literature on a firm's investment behaviour, the main determinants studied have been economic and financial determinants. These include: the output price, the capital price, the output quantity sold and, by extension, the output quantity produced (Chirinko, 1993); borrowing constraints and interest rates (Budina et al., 2000; Latruffe, 2005; O'Toole et al., 2014); the quasi-fixity of assets, irreversibility of investment, sunk costs and adjustment costs, in particular in the agricultural sector (Bokusheva et al., 2009; Chavas, 1994; Oude Lansink and Stefanou, 1997); and the influence of public policy, in particular agricultural subsidies (Bojnec and Latruffe, 2011; Sckokai and Moro, 2009). By contrast, neighbourhood effects, where neighbours have either a direct or indirect effect on individual behaviours (Wilson, 1987) have not been studied so far. One reason may be that it is usually believed that investment decisions, which are in fact input demands in the medium- or long-term, are governed by managers' profit-maximising behaviour and are thus only influenced by economic determinants. However, investment may be carried out to implement a new technology, and in this case an investment decision can be likened to the adoption of an innovation. In the agricultural literature, the importance of neighbourhood effects has recently been recognised in innovation adoption. Case (1992), for example, indicates that farmers are influenced by their neighbours when taking discrete choice decisions on the adoption of new technologies. Abdulai and Huffman (2005) show that a farmer's adoption of crossbred technology in Tanzania is positively influenced by the proximity of the farmer to other farmers using the same technology. The case of conversion to organic farming has also been studied in relation to neighbourhood effects, giving evidence worldwide of the role of neighbouring organic farms on the decision to adopt organic technology (e.g. Lewis et al., 2011; Wollni and Andersson., 2014; Läpple and Kelley., 2014). This suggests that, after technology adoption, farmers develop a degree of 'positive or negative affect' towards the new technology, which they then spread to their neighbours (Case, 1992).

Manski (1993) explains that 'neighbourhood effects' can also be termed in the literature 'peer influences', 'endogenous social effects' or 'social norms', depending on the context (sociology, social psychology, economics, health). He provides a clear definition of such effects: 'the propensity of an individual to behave in some way varies with the prevalence of that behaviour in some reference group containing the individual'. Such a 'reference group' may also be called a 'social group', where two or more people interact with one another, share similar characteristics, and collectively have a sense of unity (Turner, 1982).

Neighbourhood effects are due to interactions and information shared across agents within a group, and therefore depend on geographic proximity and network proximity. Information can be direct information or perceived information. The latter case relates to social norms theory as explained by Berkowitz (2005), as 'situations in which individuals incorrectly perceive the attitudes and/or behaviours of peers and other community members to be different from their own when in fact they are not'. It also relates to social subjective norms in the theory of planned behaviour (TPB) (Ajzen, 1985) and the theory of reasoned action (TORA) (Fishbein, 1967), where an agent's behavioural intention is influenced by his/her attitudes towards the behaviour, through social pressure or subjective norms, and by perceived behavioural control.

Empirically, there are two ways of investigating neighbourhood effects. The first is to evaluate those unobservable effects through direct revelation methods; namely, by directly questioning farmers through structured elicitation, in order to obtain measures of farmers' beliefs (e.g. Läpple and Kelley., 2013; Rehman et al., 2007). The second way is to assess observed neighbourhood effects using spatial econometric techniques that account for spatial spillovers (e.g. Wollni and Andersson., 2014; Läpple et al., 2015). Two types of spatial spillover can be accounted for econometrically: spatial dependence where values observed at a location depend on values observed at nearby locations (in other words, neighbouring effects); and spatial heterogeneity where the econometric model's coefficients vary across locations.

Here we focus on the specific role of neighbouring effects (i.e. spatial dependence) on large investment decisions that can be likened to the adoption of innovation. We assume that such decisions are observed in the data through investment spikes, which are 'large, discrete investment episodes' (Kapelko et al., 2015). Neighbourhood effects themselves may have two components: they can be effects due to neighbours' simultaneous decisions (Baerenklau, 2005; Läpple et al., 2017), that is to say farmers are immediately influenced by the current decisions of their neighbours, or they can arise from their neighbours' previous decisions (LeSage and Pace, 2009). The latter component is acknowledged by Läpple et al. (2017) in the limitations of their study of neighbourhood effects of sustainable technology adoption in the Irish dairy sector, as follows: 'farmers' technology choices are analysed at one point in time, but there is a likely possibility that farmers are influenced by previous decisions of their peers'. This issue is indeed particularly relevant in the adoption context, as not all farmers adopt an innovation at the same time. There are pioneers and followers or, more precisely, there are five stages in the technology adoption lifecycle (Beal et al., 1957): innovators, early adopters, early majority, late majority and laggards. In general, only neighbourhood effects of simultaneous decisions are accounted for in empirical studies, because accounting for neighbours' previous decisions requires panel data and dynamic spatial panel data modelling, entailing methodological difficulties. Our article contributes to the literature by assuming that it is possible to account for previous decisions without using a dynamic specification. Our strategy relies on the introduction of an explanatory variable 'investment age'. This variable measures the time elapsed since the occurrence of the last investment spike, and can capture neighbours' previous investment decisions.

The objective of our article is to examine the spatial determinants of farmers' spike investment decisions, in particular the role of neighbourhood effects arising from both simultaneous and previous decisions of neighbours, for the specific case study of dairy farmers in a region of Western France in the period 2005-2014. The article is structured as follows: Section 2 explains the empirical framework and Section 3 describes the data. Section 4 presents the empirical results. Section 5 concludes.

4.2 Empirical framework

4.2.1 Econometric model

The dependent variable y is binary, taking the value 1 if there is an investment spike (adoption of innovation) and the value 0 if not (no adoption of innovation). A probit model is therefore needed, with the latent variable y^* capturing the difference in a farmer's utility if adoption is undertaken or not. In other words, we assume that a farmer will have an investment spike if the expected utility of an investment spike (i.e. the utility of adoption) is higher than that of no investment spike (i.e. of no adoption). The general form of the probit model to be estimated is therefore:

$$\begin{cases} y_t = 1 \text{ if } y_t * > 0 \\ y_t = 0 \text{ if } y_t * = 0 \end{cases} \tag{4.1}$$

with t the time period; y_t the binary dependent variable; and y_t* the latent variable which needs to be modelled in terms of several explanatory variables and accounts for neighbourhood effects.

Neighbourhood effects are classically modelled in three possible ways (which are not mutually exclusive): including a spatial lag of the explanatory variables; including a spatial lag of the dependent variable; and including a spatial lag of the error term. Whether the latter two forms of spatial lag should be included in the model can be tested through Moran's test of spatial autocorrelation of the observations (Moran, 1948). We thus perform such a test in a classic (i.e. non-spatial) probit model (that is, without accounting for neighbourhood effects) (Kelejian and Prucha., 2001). As shown in Appendix 1, the Moran's I test statistics calculated each year indicate that there is no spatial autocorrelation in our data except in years 2008 and 2013 where the value of the statistics is very close to zero. Hence, over the full period we consider that there is, on average, no spatial autocorrelation and we will not include spatial lags of the dependent variable nor of the error term. This means that there are no neighbourhood effects arising from neighbours' current decisions. We do, however, include spatial lags of explanatory variables to account for spatial effects due to neighbours' characteristics.

As regards neighbourhood effects arising from neighbours' previous decisions, this is non-testable with Moran's I test and such effects should therefore be directly modelled. The dynamic spatial panel data model can account for these effects (Elhorst, 2010) but this model may suffer from an identification problem and is difficult to implement in practice (Anselin et al., 2008; Manski, 1993). The important contribution of this article is to propose a new model, which is easier to implement. This model relies on the spatial lag of X model (SLX), which includes spatial lags of the explanatory variables. We use the probit version of the SLX, namely the spatial lag of X probit model (LeSage, 2014). In order to account for the neighbourhood effects of neighbours' previous decisions, we include investment age among the explanatory variables that are spatially lagged. The investment age measures the time elapsed since the occurrence of the last investment spike.

The latent variable of our SLX probit model thus takes the following form:

$$y_t^* = \alpha + \alpha_Y Y_t + \alpha_{WY} W_t Y_t + \alpha_X X_t + \alpha_{WX} W_t X_t + \varepsilon_t \qquad (4.2)$$

where *t* is the time period; y_t^* is the latent variable of the SLX probit model; Y_t is the matrix of variables capturing investment age; X_t is a matrix of other explanatory variables;

$\alpha, \alpha_Y, \alpha_{WY}, \alpha_X, \alpha_{WX}$ are parameters to be estimated; ε_t is a normally distributed error term; and W_t is the spatial weight matrix.

Marginal effects are computed following Lacombe and LeSage (2018). They can be decomposed into direct effects and indirect effects. Direct effects, given by the non-lagged variables Y and X, show a change in farmer i's behaviour due to a change in the farmer i's own past investment behaviour (Y_{it}) and own current characteristics (X_{it}). Indirect effects, given by the spatially lagged variables (*WY* and *WX*), show a change in farmer *i*'s behaviour due to a change in his/her neighbour j's past investment behaviour (Y_{jt}) and neighbours' current characteristics (X_{jt}). Total marginal effects are the sum of direct and indirect effects.

We use maximum likelihood to estimate the SLX probit model. The estimation requires the specification of the spatial weight matrix W as a first step.

4.2.2 Spatial weight matrix specification

One limitation of our database is the lack of precise farm geographical location, preventing the computation of the exact distance between two farms. As commonly used in the literature, to approximate the location of a farm we use the centroid of the smallest spatial unit the farm belongs to, here the farm's municipality. To approximate the geographic proximity between farms we use the Euclidean distance between centroids (Conley and Topa, 2002; Le Gallo, 2001; Saint-Cyr et al., 2018).

We use an inverse distance spatial weight matrix (W_D) with weights $w_{ij} = 1/d_{ij}$, where d_{ij} is the Euclidean distance between the municipalities of farm *i* and farm *j*. Similarly to Läpple et al. (2017), Roe et al. (2002), and Wollni and Andersson (2014), we consider that beyond a specific distance the neighbourhood effects disappear. In other words, we assume that all spatial weights w_{ij} outside a given distance (d^*) are zero, i.e. $w_{ij} = 0$ if $d_{ij} > d^*$. Following Läpple et al. (2017), we set d^* as 10 km because at this distance all farms in our sample have at least one neighbour. Using an inverse distance matrix implies that closer neighbours have a stronger influence than do more distant neighbours, which seems to conform to the reality. Since in our sample the smallest distance between two municipality centroids is 2.5 km, we assume that two farms *i* and *j* belonging to the same municipality are at a distance of 1 km on average, meaning that we set $w_{ij} = 1$ for them.

4.3 Database

4.3.1 Database

Our application is to dairy farms in an administrative region of Western France, namely Ille-et-Vilaine, which is a NUTS3[16] region in Brittany. We use farm-level data collected annually over 2005-2014 by a bookkeeping company, the private accountancy agency CER FRANCE d'Ille-et-Vilaine. After cleaning for inconsistent observations, the usable sample includes 2,112 dairy farms observed annually over the 10-year period or less, that is to say an unbalanced sample with a total of 14,127 farm-year observations.

The sample used is a relatively good representation of the full population of dairy farms present in the French Agricultural Census data. In fact, the yearly recovery rate, which is the number of dairy farms per municipality in our sample divided by the number of dairy farms per municipality in the Agricultural Census data, is on average 77% with a standard deviation of 20% over all the municipalities. This suggests that the 'missing neighbourhood problem', where the number of neighbours in the sample used does not represent the real number of neighbours in the population due to sampling issues, mentioned by Läpple et al. (2017), is quite limited in our case.

Additional data are used in the estimation, namely data from the French Agricultural Census at the municipality level regarding the dairy farm population. The values of the Agricultural Census in 2010 are used for the whole period covering our farm-level data (2005-2014) since no other Agricultural Census was implemented during this period.

4.3.2 Dependent variable: definition of investment spikes

The dependent variable of our SLX probit model takes the value 1 if there is an investment spike and the value 0 if not. We consider that an investment spike occurs if the farm's gross investment in buildings, machinery and materials (between years t and t-1), divided by the capital value (of year t-1) exceeds a specific threshold of β per year. Here we consider the threshold to be 20%, enabling us to focus on large and significant investments. This choice of

[16] 'The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU' (https://ec.europa.eu/eurostat/web/nuts/background).

threshold value is based on local experts' advice and on the literature (Kapelko et al., 2015; Power, 1998; Licandro et al., 2004). Hence, the dependent variable is a dummy variable taking the value 1 if the farm's investment exceeds 20% of the value of the capital stock and 0 if not. Different thresholds β could be used to define investment spikes, and Table 4.1 shows the distribution of spikes depending on three thresholds (15%, 20% and 25%). For the selected threshold (20%), the share of spikes in total farm-year observations is 15.7%. This figure varies between 19.4% and 12.9% across the three different thresholds, as well as the number of farms with spikes (last part of Table 4.1). In order to check for the robustness of our results, the estimations will also be performed for the two other thresholds (15% and 25%).

TABLE 4. 1 : Comparison of investment spike definitions

	Threshold β		
	15%	20%	25%
Number of observations over the period:	14,127	14,127	14,127
no spike (a)	11,382	11,902	12,298
spike (b)	2,745	2,225	1,829
Share of spikes in total observations (%) (= b × 100 / a + b)	19.4	15.7	12.9
Share of spikes' value in total investment value (%) (= aggregated value of all investment spikes over the period × 100 / total investment value over the period)	88.3	80.2	72.4
Number of farms with:			
0 spike	492	641	803
1 spike	792	869	871
2 spikes	582	466	364
3 spikes	203	123	67
4 or more spikes	43	13	7

Note: the threshold value β is when a farm's investment exceeds β% of the value of capital stock.

Source: The authors, based on CER FRANCE Ille-et-Vilaine

4.3.3 Explanatory variables

As explained above, we account here for the neighbourhood effects of neighbours' previous decisions by including in the explanatory variables some proxies for the investment age, Y_t. Following Kapelko et al. (2015) and Licandro et al. (2004), for each farm-year observation *i*,*t* we compute the number of years elapsed since the most recent spike has occurred for farm *i*. We then build investment age dummies ranging from 1 to 6-or-more years. For example, the dummy variable 'Investment age 1 year old' takes the value 1 if the most recent investment spike took place one year ago, or, in other words, if one year has elapsed between two investment spikes.

The other explanatory variables, X_t, are based on the literature on agricultural technology adoption (Barham et al., 2004; Läpple et al., 2017; Roussy et al., 2017; Sauer and Zilberman, 2012) and investment behaviour (Budina et al., 2000; Latruffe, 2005; O'Toole et al., 2014; Storm et al., 2014). They include the farm's dairy herd size, livestock density (proxied by the number of livestock units per hectare of utilised agricultural area), labour to capital ratio, degree of specialisation in milk production (proxied by milk gross margin divided by total gross margin), and the reliance on fodder maize (proxied by the share of fodder maize in forage area). These variables are observed yearly for each farm and are measured at the farm level, while two additional explanatory variables are observed in 2010 only (as they are extracted from the Agricultural Census) and are measured for the municipality where the farm is located: dairy cow density and dairy farm density.

Finally, we include four control variables. One control variable is the number of occurrences of the farm during the period (to control for the fact that the probability of observing an investment spike increases with the number of times that the farm appears in the sample). The three other control variables aim at controlling for economic conditions: the farm's milk price; a dummy variable for the year 2008; and the farm's rate of growth of milk quota. Both latter variables allow for the announcement of the termination of the EU's dairy quota policy to be taken into account.

To avoid endogeneity issues, the variables dairy herd size, livestock density, labour to capital ratio, milk specialisation, and reliance on fodder maize, are included lagged over one period (i.e. *t*-1), while the other variables are used in *t*.

The descriptive statistics of all explanatory variables are presented in Table 4.2.

TABLE 4. 2 : Description and summary statistics of explanatory variables

Variable		Mean	Standard deviation	Min	Max
Investment age (Y)					
Investment age 1 year old	Dummy = 1 if 1 year between two investment spikes	0.117	0.321	0	1
Investment age 2 years old	Dummy = 1 if 2 years between two investment spikes	0.096	0.295	0	1
Investment age 3 years old	Dummy = 1 if 3 years between two investment spikes	0.075	0.263	0	1
Investment age 4 years old	Dummy = 1 if 4 years between two investment spikes	0.059	0.235	0	1
Investment age 5 years old	Dummy = 1 if 5 years between two investment spikes	0.043	0.202	0	1
Investment age 6 years old	Dummy = 1 if 6 years between two investment spikes	0.042	0.205	0	1
Other explanatory variables (X)					
Dairy herd size	Number of dairy cows in the farm	48.7	19.5	7.6	198.5
Livestock density	Livestock units per hectare of agricultural utilised area of the farm	1.6	0.4	0.5	7.8
Milk specialisation	Milk gross margin/total gross margin of the farm	0.62	0.15	0.01	1
Labour to capital ratio	Number of annual working units per Euro of capital of the farm	0.000029	0.000181	0	0.017396
Reliance on fodder maize	Share of fodder maize in forage area of the farm	39.2	12.6	0	100
Dairy cow density	Number of dairy cows per km² in the farm's municipality	0.41	0.15	0.05	0.87
Farm cow density	Number of dairy farms per km² in the farm's municipality	0.0059	0.0025	0.0007	0.0168
Control variables					
Number of occurrences	Number of times that the farm appears in the sample	7.4	1.8	3	9
Milk price	Milk price of the farm in Euros per 1,000 litres	316.4	28.4	251.9	511.4
Dummy year 2008	Variable taking value 1 for year 2008 and 0 otherwise	0.1253	0.3311	0	1
Rate of growth of milk quota	Change in milk quota between years *t* and *t*-1, divided by the quota in *t*-1	0.043	0.309	-0.926	15.56

Note: 'Dairy cow density' and 'Farm cow density' are observed in year 2010 and taken from the Agricultural Census, while all other variables are observed each year at the farm level and taken from the farm-level accountancy database during 2005-2014. The number of observations for each variable is 14,127.

Source: The authors, based on CER FRANCE Ille-et-Vilaine

4.4 Results and discussion

4.4.1 Spatial versus non-spatial probit model

We estimate the SLX probit model of equations (4.1) and (4.2) on the pooled sample (i.e. all years pooled together). Before presenting the results, we firstly compare the performance of the SLX probit model with that of the non-spatial probit model in order to assess whether accounting for spatial effects improves the quality of the model prediction.[17] The comparison is based on the percentage of correctly predicted observations using Wooldridge (2015):

$$\hat{p} = (1-\theta)\widehat{p_0} + \theta\widehat{p_1} \quad (4.3)$$

where $\hat{p}$ is the overall percentage of correctly predicted observations, $\widehat{p_0}$ is the percentage of correctly predicted observations with no spike, $\widehat{p_1}$ is the percentage of correctly predicted observations with spike, and θ is a specific threshold.

This threshold θ may be defined as 0.5 but this can lead to misleading results, because it is possible to get high percentages of correctly predicted observations even when the least likely outcome (spike or no spike) is very poorly predicted (Wooldridge, 2015). This is the case for our sample where there are only 15% of spike observations. Thus, we may use 0.15 as the value for the threshold θ, but this would increase the number of predicted observations with spike and would incorrectly predict the observations with no spike. Thus, in terms of the overall percentage correctly predicted, we may do worse than when using the 0.5 threshold.

A third possibility, suggested by Wooldridge (2015), is to choose the threshold such that the number of predicted spikes is exactly equal (or close) to the number of observed spikes in the sample. In our case, after several trials we found that the value 0.18 for the threshold θ is the most appropriate for our sample.

Table 4.3 presents the results of the percentage of correctly predicted observations for several thresholds tested. One can note that, in all cases, the SLX probit model performs better, even if marginally, than the non-spatial probit in terms of predictive power. This implies that taking

[17] Results of the non-spatial probit are shown in Appendix 2.

into account spatial effects improves the accuracy of the model, as found by Läpple et al. (2017).

TABLE 4. 3 : Comparison of model performance

Threshold θ	Percentage of correctly predicted observations $\hat{p}$ with the SLX probit	Percentage of correctly predicted observations $\hat{p}$ with the non-spatial probit
0.18	68.99015	68.84245
0.15	56.54231	55.40857
0.5	84.26331	84.23519

Note: the threshold value θ and the percentage $\hat{p}$ refer to equation (4.3).

Source: The authors, based on CER FRANCE Ille-et-Vilaine

4.4.2 Results of the spatial probit model

Table 4.4 presents the results of the spatial probit model, namely the SLX probit model, in terms of marginal effects. Firstly looking at results for the investment age (variables *Y*), we find that all direct marginal effects are negative. This indicates that, for a farm *i*, having an investment spike in previous years (whatever the year(s)) decreases the probability of having an investment spike in the current year *t*. This is an intuitive result as farms do not innovate each year. It takes time to fully implement an innovation and large investments result in adjustment costs for the farm (Bokusheva et al., 2009; Levi et al., 2017). Also conforming to intuition, the probability of having an investment spike is reduced more when an investment spike has occurred the year before (*t*-1) than when it has occurred in earlier years (*t*-2 up to *t*-6). Adjustment costs are indeed stronger in the first year(s) following an investment.

More importantly, when looking at the indirect marginal effects of investment age, we found that the probability of observing an investment spike significantly increases (by about 12%) if investment spikes occur in neighbouring farms in the previous year (*t*-1). There are no significant effects for earlier years. In other words, farmers influence their neighbours with a time lag of one year only, revealing that farmers keep in mind mainly the most recent investment decisions of their neighbours. This is consistent with findings in experimental economics trying and eliciting subjective probability. They find that individuals are asymmetrically influenced by good and bad events and by late and recent events (Tversky and Kahneman, 1981). However, our results show that overall the total (own plus neighbours') effect of investment age of one year old is negative, suggesting that the positive influence of neighbours does not compensate for the negative impact of adjustment costs of previous investments on own farm.

Looking at the direct effects for the other explanatory variables (*X*), results indicate that dairy herd size decreases the probability of having investment spikes, while livestock density, milk specialisation, and labour to capital ratio increase it. There is no significant effect of the farm's own reliance on maize fodder on the probability of observing an investment spike. There is also no significant effect of the municipality's variables, namely dairy cow density and dairy farm density in the *i*-th farm's municipality. In addition, the higher the labour to capital ratio, the higher the probability of investing substantially, suggesting the need to substitute labour for capital.

The result on dairy herd size indicates that each additional dairy cow on farm *i* decreases the probability of observing an investment spike by 0.032% on this farm *i*. Such a negative effect contradicts with previous literature findings on technology adoption, that bigger farms innovate more (Barham et al., 2004; Feder et al., 1985; Läpple et al., 2017). In our sample it seems that what matters is production intensity, captured through livestock density and milk specialisation. More production-intensive farms are more likely to invest large amounts, suggesting that innovative investments are influenced more by farm technology type (highly intensive farms vs. less intensive farms) than by farm size.

However, although the direct effect of dairy herd size is negative, the total (own plus neighbours') effect is not significant. In fact, among the *X* explanatory variables, only milk specialisation has a significant indirect (i.e. neighbours') effect on the probability of observing an investment spike. This effect is negative, indicating that the degree of specialisation of farm *i*'s neighbouring farms in milk production decreases the probability that farm *i* invests heavily. Overall, the total (direct plus indirect) effect is also negative, suggesting that the probability of a farm making an investment spike is driven more by the specialisation degree of the farm's neighbours than by its own degree of specialisation. The negative impact of the neighbouring farms' specialisation on other farms' investment may be due to farmers fearing strong competition from highly specialised farms and thus curbing their own investment behaviour, as suggested by local experts.

Finally, regarding the control variables, as expected, the greater the number of occurrences of a farm in the sample, the higher the probability of observing an investment spike for this farm. Own milk price also has a significant effect on a farm's probability of an investment spike;

the effect being positive. This is in accordance with the theory of investment behaviour that investment is driven by output price (Elhorst, 1993; Femenia et al., 2017; Sckokai and Moro, 2009). Both variables used to control for the effect of the end of the dairy quota policy have a positive effect on own farm's investment suggesting, as expected, that quota removal lifts the constraints on a farm's expansion (Ang and Oude Lansink, 2014; Levi and Chavas, 2018).

The estimation of the SLX probit model was also performed on two alternative dependent variables, where the investment spike is defined with two different thresholds β (15% and 25%). Results (not shown here) confirm the findings described above.

TABLE 4. 4: Results of the spatial probit model (Marginal effects)

	Direct effects (Y, X)		Indirect effects (WY, WX)		Total effects	
	Marginal effect	Standard error	Marginal effect	Standard error	Marginal effect	Standard error
Investment age (Y)						
Investment age 1 year old	**-1.17686*****	0.19512	**0.11152***	0.05011	**-1.06534*****	0.20145
Investment age 2 years old	**-0.05353*****	0.01166	-0.03588	0.05389	-0.08941	0.05514
Investment age 3 years old	**-0.07025*****	0.01307	0.00041	0.05738	-0.06984	0.05885
Investment age 4 years old	**-0.03672*****	0.01418	0.01880	0.05974	-0.01792	0.06140
Investment age 5 years old	**-0.04710*****	0.01610	0.01380	0.06784	-0.03330	0.06972
Investment age 6 years old	**-0.04900*****	0.01609	0.11815	0.05018	0.06915	0.05270
Other explanatory variables (X)						
Dairy herd size	**-0.00032*****	0.00016	0.00080	0.00077	0.00048	0.00079
Livestock density	**0.00020***	0.00009	-0.00030	0.00030	-0.00010	0.00031
Milk specialisation	**0.07492***	0.02275	**-0.22781****	0.07294	**-0.15289*****	0.07641
Labour to capital ratio	**137.69652***	54.666	0.81132	98.97394	138.50784	113.06729
Reliance on fodder maize	-0.00347	0.02795	-0.02864	0.10225	-0.03211	0.10600
Dairy cow density	-0.0037	0.03677			-0.0037	0.03677
Farm cow density	1.47643	2.16637			1.47643	2.16637
Control variables						
Number of occurrences	**0.00837*****	0.00177			**0.00837*****	0.00177
Milk price	**0.00061*****	0.00012			**0.00061*****	0.00012
Dummy year 2008	**0.03633***	0.01137			**0.03633*****	0.01137
Rate of growth of milk quota	**0.03691*****	0.01882			**0.03691*****	0.01882

*Notes: *, **, ***: significance at the 10, 5, 1% level.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

4.5 Concluding remarks

This article investigates the spatial determinants of farmers' investment, in particular the role of neighbourhood effects. We take the specific case of dairy farmers in a region of Western France during the period 2005-2014. Our first contribution is to the literature on investment since it allows, for the first time, a better understanding of how farmers' investment decisions are influenced by their neighbourhood. Here, large investment decisions are considered, namely investment spikes, allowing us to link our approach to the literature on adoption of innovation. Our analysis relies on a spatial lag of the X (SLX) probit model. Our second contribution is to the literature on innovation adoption, since we not only account for neighbourhood effects arising from neighbours' simultaneous decisions but also for neighbourhood effects arising from the previous decisions of neighbours. To do this, we include in the explanatory variables dummies proxying investment age.

Moran's I results do not reveal the existence of neighbourhood effects due to simultaneous decisions of neighbours in the occurrence of farms' investment spikes. However, results of the SLX probit model show the existence of neighbourhood effects due to the previous decisions of neighbours, confirming that farmers take account of their neighbours' decisions when they make substantial investment decisions. Indeed, the results indicate that the probability of observing an investment spike on a farm increases if investment spikes occurred on neighbouring farms in the year before. By contrast, neighbours' decisions in less recent years do not affect a farm's own decisions. Interestingly, the positive effect of neighbours' last year investment does not compensate for the negative effect of own farm's last year investment. This latter negative effect can be explained by adjustment costs faced by farmers when implementing a large investment.

From a policy point of view, our investigation suggests that neighbourhood effects are a positive multiplier in farms' large investment decisions, as found by Läpple et al. (2017) for the case of sustainable technology adoption in the Irish dairy sector. Increasing farmers' direct interactions or indirect information sharing could thus provide incentives to invest. However, interactions should not relate solely to which investments to implement, but also to how to implement them in such a way that adjustment costs are limited. Demonstration events and extension services are therefore crucial. This is particularly true in a period of changing economic conditions such as those faced by our sample's dairy farmers: our estimation results confirm that the progressive elimination of the EU's dairy quota policy triggered farms' large investments.

There are limitations to our study due to data constraints. Firstly, we proxied neighbourhood effects by geographic proximity but we do not know exactly how farmers communicate with each other; for example, which network they mostly use. Network proximity would be a more complete measure of neighbourhood effects, especially in a developed country where communication channels are well developed and allow for distances to be ignored. Conley and Topa (2002) consider, for example, a social economic distance instead of a physical distance. Secondly, we did not include information about farmers' education, experience, or age due to a lack of data, although such information may play an important role in the adoption of innovation as shown, for example, by Foltz and Chang (2002).

This is the first study to consider the role of neighbourhood effects on farmers' investment behaviour. Further research could go beyond the neighbourhood effects studied here, which are Manski (1993)'s endogenous effects of social norms. Manski (1993) suggested two other types of effects of social norms, namely exogenous effects and correlated effects. Exogenous (or contextual) effects of social norms imply that the propensity of an individual to behave changes in some way with the exogenous characteristics of the social group that the individual belongs to. For example, certain socio-economic groups are more likely to do certain things, such as rich people being more likely to play golf. In the case of farms' investment decisions, organic farms could be one such social group. As for the correlated effects of social norms, they mean that individuals belonging to the same social group tend to behave similarly because they face similar institutional environments. In the case of farms' investment decisions, this would mean studying, for instance, the role of the downstream sector (e.g. having a contract with a specific dairy) and upstream sector (e.g. being distant from machinery salesmen or farmers' associations for shared machinery). One possibility would be to build the spatial weight matrix based on the relative economic distance matrix defined by Elhorst and Halleck Vega (2017) or on the social economic distance defined by Conley and Topa (2002).

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Appendices

TABLE 4. 5: Results of the simple probit model computed for each year

	2006	2007	2008	2009	2010	2011	2012	2013	2014
Investment age (Y)									
Investment age 1 year old	-	-4.91255	-5.08163	-7.33735	-4.85757	-4.65951	-4.82358	-4.94731	-4.97371
Investment age 2 years old	-	-	0.00323	-0.25565**	-0.46411***	-0.45460***	-0.38121***	-0.26929***	-0.23152
Investment age 3 years old	-	-	-	-0.66301***	-0.16273	-0.19507	-0.56508***	-0.36557***	-0.41005**
Investment age 4 years old	-	-	-	-	-0.21682	-0.27154**	-0.20304	-0.28943***	-0.11878
Investment age 5 years old	-	-	-	-	-	-0.40555***	-0.21822	-0.54962***	-0.01523
Investment age 6 years old	-	-	-	-	-	-	-0.20154	-0.44702***	-0.31502**
Other explanatory variables (X)									
Dairy herd size	-0.00536*	-0.00210	-0.00364	-0.00332	-0.00280	-0.00306	0.00096	-0.00159	0.00686***
Livestock density	0.00029	0.00088	0.00074	0.00056	0.00011	0.00028	0.00038	-0.00027	0.00160
Milk specialisation	0.45226*	0.00911	0.52617***	0.51956**	0.09898	-0.11257	-0.06607	0.07078	-0.31860
Labour to capital ratio	-1203.21416	508.47198*	1407.24148***	1718.34427	816.32559***	738.1532**	3077.48166***	2183.86235***	6876.31581***
Reliance on fodder maize	0.22054	0.27055	0.55296**	0.20607	-0.42631	0.37547	0.060962	0.11145	-0.78447
Dairy cow density	-0.50630	-0.29326	0.80650***	0.24210	-0.80478*	-0.09451	-0.23900	-0.11649	0.01295
Dairy farm density	5.48854	25.53906	-41.71528***	-21.477841	22.45626	11.49690	27.02154	-17.70319	-13.44942
Control variables									
Number of occurrences	0.02561	-0.00276	0.01905	0.03474	0.06488***	0.03662	0.07144***	0.07402***	0.05830**
Milk price	0.00016	-0.00169	0.00168	0.00323***	0.00121	0.00157	0.00093	-0.00164	-0.00329
Rate of growth of milk quota	0.03761	0.14666*	1.66213***	0.10844	0.92145**	0.69018*	0.64377794**	-0.03835	0.09072
Intercept	-2.00094*	-0.83015	-3.83853***	-2.52285***	-2.35761***	-2.43766***	-2.53320***	-0.55877505	-0.58270
Log-Likelihood	-574.23062	-639.11225	-771.83662	-795.92518	-602.32078	-602.32078	-669.17094	-584.003572	-385.92311
LR test	44.36435	70.13235	150.67446	175.61059	114.057412	114.057412	113.528072	87.3814471	68.02617
Moran's I	0.00210	-0.00779	0.01748***	0.00048	-0.00274	-0.00311	0.00163	0.01453**	-0.00613

*Notes: *, **, ***: significance at the 10, 5, 1% level.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

TABLE 4. 6: Results of the non-spatial probit model estimated for the pooled sample: coefficients

	Coefficient	Standard error
Investment age (Y)		
Investment age 1 year old	-5.24745682	24.9270562
Investment age 2 years old	**-0.18063396*** **	0.05020276
Investment age 3 years old	**-0.24735028*** **	0.05722879
Investment age 4 years old	-0.07058377	0.05985053
Investment age 5 years old	-0.08936631	0.06806766
Investment age 6 years old	-0.06794521	0.06850298
Other explanatory variables (X)		
Dairy herd size	-0.00063454	0.00071123
Livestock density	**0.00071737***	0.00040099
Milk specialisation	0.12593287	0.092617
Labour to capital ratio	**626.528045*** **	143.222575
Reliance on fodder maize	-0.01861549	0.12048116
Dairy cow density	-0.12637196	0.15220741
Farm cow density	3.05067642	9.27748022
Control variables		
Number of occurrences	**0.03378292*** **	0.00765278
Milk price	**0.00228592*** **	0.00049881
Dummy year 2008	**0.17879209*** **	0.04052872
Rate of growth of milk quota	**0.16978577*** **	0.04336643
Intercept	**-2.67218262*** **	0.20619301

*Notes: *, **, ***: significance at the 10, 5, 1% level.*

Source: The authors, based on CER FRANCE Ille-et-Vilaine

CHAPTER 5.

General discussion and conclusion

5.1 Summary and discussion of the findings

The aim of this thesis was to contribute to a better understanding of the firm investment behaviour with an application to the Brittany dairy sector. The objective was to analyse the factors influencing investment decisions, particularly the role played by agricultural policies, farm managerial performance and social interactions. Firstly, in chapter 2, the thesis intended to document the effects of agricultural policy on farm investment, with a focus on the ending of European Union (EU) dairy quotas policy. This chapter analysed how the "soft landing" policy change, which consisted in a progressive increase of the dairy quota reference by 2% in 2008 and then 1% between 2009 and 2015 in all EU member states, increased the incentive to invest and how this effect is heterogeneous across farms and time. Secondly, in chapter 3, the thesis investigated the role of farm performance in farmers' investment decisions, while accounting for farm heterogeneity, by considering two farm types, those with high and those with low capital intensity. Thirdly, in chapter 4, the thesis studied the spatial determinants of farmers' investment, in particular the role of neighbourhood effects.

As regards the study in chapter 2, some works have been done on the role of public policy in farm investment, such as the impact of the Common Agricultural Policy (CAP) Single Farm Payment (SFP) on farm investment (Sckokai and Moro, 2009), the impact of subsidies in a transition to a market economy in the period 1994-2003 in Slovenia (Bojnec and Latruffe, 2011) and the impact of decoupled government transfers on a sample of Kansas farms (Serra et al., 2009). However, recently, a sharp policy change happened, which is the milk quota removal in EU, and this has not been largely studied in the investment literature. However, this policy reform could induce large structural changes in the farm dairy sector, which need to be anticipated.

To answer this question, we rely on the neoclassical theory of optimal capital accumulation (Hall and Jorgenson, 1969) and formulate a dynamic optimization problem for a farmer making production and investment decisions. Our model allows for the presence of adjustment costs (allowing adjustments to have asymmetric effects between capital increases and capital decreases (e.g., as found by (Lansink and Stefanou, 1997)) and allows examine the evolving role of dairy quotas in farm investment incentives. Also, this chapter introduces the quota constraint, allowing computing the shadow price of quota. The panel data analysis also allows to document heterogeneity in dynamic adjustments made over time and across farms.

As seen in chapter 2, many factors affect capital formation. Under a "soft landing" policy, we expect the shadow price of quota to decline in response to an increase in quota, providing an incentive to expand production. However, this incentive may be muted by the presence of adjustment costs. In addition, other factors also play a role (including the changing market price of milk). As a result, the effects of the quota termination and of the "soft landing" policy on farm investments are difficult to know a priori. Chapter 2 is intended to provide new information on these issues. The results show that farmers' incentives to invest have increased since the announcement of the removal of the EU dairy quotas and that this policy reform has induced structural changes in the farm dairy sector by favouring dairy farms that are more specialized, use more intensive production systems and have higher capital intensity. Also, we found evidence that the quota removal effects vary with the farmer's age (e.g. with his/her life cycle), meaning that it is important to account for farm life cycle in farm investment decision as found by Ahituv and Kimhi (2002) and by Gale Jr (1994). Moreover, the results also showed that farms with high labour productivity have a higher shadow cost of the quota than farms with low labour productivity, underlining possible interactions between managerial ability and adjustments to policy shift. This meant that heterogeneity in farmer's ability (probably linked to farmer's experience, age and formation) could play a role in farms investment behaviour. This heterogeneity is investigated further in chapter 3.

Chapter 3 investigates the role of farm performance on investment decisions by estimating an adjustment cost model of investment. While the literature on farm investment behaviour usually excludes the role played by organisational factors such as managerial performance from the analysis, in theory, the effect of farm performance on investment is ambiguous. On the one hand, high farm performance (for instance better productivity inducing better income) can allow farmers to afford investment in the future, in line with the accelerator effect; on the other hand, farmers with a highly performing farm may postpone investment in order to avoid adjustment costs that would decrease their performance in the short term.

Moreover, even if many theoretical and empirical studies point out the role of farm performance, especially, the role of capital productivity, on farm investment behaviour, other indicators, more related to managerial performance, such as farm milk gross margin or operational expenses per 1,000 litres of milk, may capture different types of farmer abilities. Distinguishing these indicators is an important contribution of chapter 3, because, in our case, it allowed disentangling tax incentive to invest (productivity of capital) and disincentive to invest due to adjustment costs. The other contribution of chapter 3 is that, in addition to the full sample, two farm types are considered, one with high and one with low capital intensity.

First, results show that smoothing farm investment over time is, on average for the full sample, an optimal strategy in the presence of adjustment costs, as for example reported by Gardebroek and Lansink (2004). However, the effect of performance on investment behaviour differs between the two farm types. Indeed, high capital intensity (HCI) farms and low capital intensity (LCI) farms may prefer not to invest in order to avoid adjustment costs in the short term, but the magnitude of this effect is higher for low capital intensity farms. Also, on average, the coefficient for the output to capital ratio is significant and positive for both sub-samples, but the magnitude of this effect is higher for LCI farms than for HCI farms. This indicates that LCI farms tend to invest, in the next period, more than LCI farms when the ratio of output to capital in the current period is higher. This may reveal a standardisation trend in terms of technology in this specialised dairy region. Our findings highlight that farmers' heterogeneity needs to be accounted for in modelling investment behaviour. It allows differentiated strategies to be revealed and can help design targeted policies aimed at encouraging investment. For example, if the objective is to preserve traditional farming structures (i.e small and medium family farms), then regional policy measures need to focus on how to act in this new context. Likewise, if the objective is to accompany or spread up structural changes, regional policy need to use available policy tools in this way. For instance, depending on the societal goal, a policy subsidizing investment could be targeted to specific farms based on characteristics such as performance, capital intensity, etc. Moreover, we hypothesize that the positive sign of the coefficient for the output to capital, is reinforced by the French business taxation system, which encourages farms to invest in order to reduce their tax base in case of high incomes and hence reduce corporation tax and social contributions.

Chapter 4 examines the spatial determinants of farmers' spike investment decisions, in particular the role of neighbourhood effects, arising from both simultaneous and previous decisions of neighbours, for the specific case study of dairy farmers in a Western French region. Investment decisions are measured with investment spikes, enabling linking the analysis to the literature on adoption of technology innovation. The main contribution is to account for the effect of previous decisions of farmers' neighbours, with the help of a spatial probit econometric model that includes investment age. Results show that farmers are not immediately influenced by the simultaneously made decisions of their neighbours, but rather by the decisions of their neighbours in the year before. However, this positive influence does not compensate for the negative effect of own previous investment decisions. This latter negative effect can be explained by adjustment costs faced by farmers when implementing large investment. From a policy point of view, our investigation suggests that neighbourhood effects are a positive multiplier in farms' large investment decisions, as found by Läpple et al. (2017) for the case of sustainable technology adoption in the Irish dairy sector. Increasing farmers' direct interactions or indirect information sharing could thus provide incentives to invest.

5.2 Recommendations

Some recommendations for policy makers and stakeholders in the dairy sector may be put forward from the results obtained in this thesis. The following main recommendations could be drawn:

As said above in chapters 2 and 3, results show that it is crucial to account for farm heterogeneity in modelling investment behaviour because it allows foreseeing structural changes and target policy recommendations to farm types. Results in chapter 2 show that farmers' incentives to invest have increased since the announcement of the EU dairy quota removal, and that this policy reform has induced structural changes in the farm dairy sector by contributing to the trend toward larger, more capital intensive and more specialized dairy farms. Also, chapter 3 results reveal a standardisation trend in terms of technology in this specialised dairy region. From a policy viewpoint, our investigation suggests that this policy reform affects the evolving structure of agriculture. However, milk quotas were originally instated and administratively managed (favouring small farms and young farms in the attribution of milk quotas), in part, to protect farmers from rapid structural changes in agriculture (e.g., increasing farm sizes, frequent farm exits, and shifts in production to more productive areas). Regional policy measures should account for this heterogeneity and implement appropriate policies that aim at maintaining dairy production as well as a balanced land planning. On the opposite, if the objective of public policies is to accompany or spread up the structural changes, regional policy needs to use appropriate tools. For instance, depending on the societal goal, one policy issue is to decide on which criteria to allocate investment subsidies, for instance according to farms characteristics such as performance, capital intensity, etc. Moreover, we suggested in chapter 3 that the French business taxation system encourages farms to invest (in order to reduce their tax base in case of higher incomes and so reduce corporation tax and social contributions). This point could be a potential leverage to influence farms investment behaviour.

Our investigation in chapter 4 suggests that neighbourhood effects play a role in the occurrence of investment spikes and are positive multiplier of investment decisions, which should be used by stakeholders and policy makers. Whatever the technology promoted by stakeholders or policy makers, one should account for the way farmers are influenced by their neighbourhood. In other words, they should know that increasing farmer's direct interaction or indirect information sharing could provide incentives to invest. In addition, the probability for a farm to make an investment spike is more driven by the specialisation degree of the farm's neighbours than by its own degree of specialisation. The negative impact of the neighbouring farms' specialisation on other farms' investment may be due to farmers fearing strong competition from highly specialised farms and thus curbing their own investment behaviour. These two findings show the importance of taking into account farm's neighbours.

5.3 Limits

The reader should take into consideration that there are some limitations in our studies from both a theoretical and methodological point of view, and also due to data limitation.

From a theoretical point of view, we made some assumptions to keep the model simple but some of these assumptions could raise problems. Firstly, in chapter 2, we assumed naïve expectations about market prices based on Chavas (2000) who presented evidence that naïve expectations are the most common form of expectations on livestock farms. However, the financial crisis in 2009 showed that milk prices can drop to a very low level and can make dairy farmers have doubts about their future. So, milk price level and volatility could strongly influence risk perception and price anticipation. Farmers may change their price expectations to better adapt to the new context. Following Chavas (2000)'s methodology, it may be relevant to document the way farmers made their milk price expectations during this period, to verify whether the assumption made in chapter 2 is robust.

Secondly, in chapter 3, we assumed that milk price is constant over the period of study, which is in reality not the case. However, lifting this assumption brings modelling complexities. We attempted to develop a theoretical model with varying prices (see Appendix A.1), but we encountered difficulties in estimating such a model because it does not allow identifying the price effect on farm investment, since all parameters is multiply by the price (see equation (9) in Appendix A.1 . Another way to lift this assumption of constant milk price over the years, is to consider two sub-periods in the estimation strategy, before and after 2009 (i.e. 2005-2008 and 2008-2014), but our estimation suffers from a lack of time dimension, as we use GMM estimation techniques, using instrument lags over two periods. Indeed, to see a significant difference between the two periods (2005- 2008 and 2008-2014), we need a higher time dimension, especially for the period 2005-2008, because when using GMM estimation techniques with instrument lags over two periods we only have two years for the estimation, which is not sufficient.

Thirdly, in chapter 3, in the empirical estimation strategy, we introduced a performance parameter in an ad-hoc way. Indeed, the performance variable introduced is not deduced from the theoretical model. However, it could be interesting to find a way to account for the performance parameter in the theoretical framework. Here also we tried and built a new theoretical framework introducing performance in the theoretical framework (see Appendix A.2) but we gave up due to the following shortcomings: i) we made the assumption that performance is a function of capital only. However, performance (i.e. managerial performance) also depends on workers, their experiences, age, etc.. ii) There is a problem of endogeneity, since, whatever the performance parameter used, performance is already a result of the farm maximisation program. Moreover, this could induce difficulties in the estimation of the parameters, since there is a possible correlation between capital and performance (see equation 20 in Appendix A.2).

Fourthly, we assumed that farmers were risk neutral, although some literature has shown that some farmers are risk averse (Liu and Meyer, 2013; Young, 1979). Introducing risk in the modelling strategy is hence one avenue for future research. Moreover, along the three chapters, we worked on data available at the farm level rather than at the household level. As the farmers' attitude towards the risk depends on several factors including the balance between savings and investment, time preferences, and also household wealth (assets), it would be more appropriate to work at household-level rather than at farm-level. Moreover, in the Brittany dairy region, many dairy farms are family farms managed by households. However, in this case, the theoretical framework of the analysis should be based on the household's utility maximisation framework as already done in the literature (Benjamin and Kimhi, 2006; Chavas et al., 2005; Petrick, 2004). Specific data would however be needed, which are heavily lacking at this scale.

Another category of limitations of studies on farm investment deals with the lack of data. In our case, we do not have precise information about real investment in the database. So, in the three chapters, we could only use capital change, which is the difference between capital in year *t* and capital in year *t*-1, instead of real investment. Our appraisal of investment behaviour could be improved with real investment because it does not contain capital depreciation. However, the advantage of using capital change to proxy investment is that we can study the farm investment behaviour accounting for disinvestment as well.

In chapter 4, we did not have the precise farms location and we approximated their location by the centroid of the municipality. However, overcoming this approximation would help better measuring neighbourhood effects. Moreover, we did not know the exact way farmers communicate with each other, that is to say, which network they mostly use for example, so we used spatial proximity only as a proxy for social network. In fact, neighbourhood effects could be linked to the actual networks rather than to the physical distance, especially in developed countries where communication channels (ICT) are well developed and allow to get rid of the distance.

Another limitation of chapter 4 is the lack of information about farmers' education, farmers' experience, and farmers' age, which may play an important role in the adoption of innovation as shown by Foltz and Chang (2002). More precisely, in our database, information about farmers' education is not available, and information on farmers' experience and age is available only for a limited number of farms. This is why farmers' age is used in chapter 2 and 3, which studies only a sub-sample of the overall sample used in chapter 4.

In line with this limitation, it is important to account for farm life cycle in the modelling strategy, because some studies have shown that farm investment behaviour differs according to the position of the farmers in their farm life cycle. This position influences investment needs and the source of financing. Boehlje (1973) identified three stages of the farmer's life cycle: (1) entry/establishment, (2) growth and survival, and (3) disinvestment. The life cycle model suggests that farms of entering farmers are growing over time, while older farmers diminish their operation size to prepare for the retirement. In line with it, Gale Jr (1994) shows for U.S. farm sector, that older and more experienced farmers tend to reduce farm size, while new farmers have smaller farms, grow faster, and are less likely to own farmland. In addition, farmers expand by investing in land, machinery, livestock or other inputs during the growth and survival stage, while they disinvest later in their career.

Also, it could be very interesting to have details about the type of investment farms made, that is to say, to know more about farm innovation investments (if they buy a new milking robot, a new building, a new tractor). This would allow being more precise in studying farmers investment behaviour and in anticipating farmers' need. Unfortunately, we did not have access to this kind of precise data.

5.4 Suggestions for further research

As said along chapters 2, 3 and 4, this thesis contributes to the literature in agricultural economics. However, these studies suffer from some shortcomings (see section 5.3). As knowledge is infinite, extra work is needed to improve our knowledge on farm investment behaviour. I propose further investigations from a wide angle and wrote this section in order to suggest avenues for future research.

- After analysing the impact of the termination of dairy quota in Brittany in chapter 1, a possible extended work could be to study the influence of the end of dairy quotas in 2015 in order to complete the analyse. This study could help stakeholders and policy makers to have an idea of what is happening in terms of structural changes and to anticipate what will happen in the future. This study relies on the availability of data from 2015 to 2018. Furthermore, it is unclear whether similar findings (i.e. to chapter 2) would apply to other EU regions. The effect of the quota removal on investment behaviour and production could differ across countries for three reasons. Firstly, the rule of quota allocation is different across countries. Some countries have organized a quota market such as in England, and some are administratively managed such as in France. Under freely tradeable quotas, more efficient farms can buy quotas from less efficient farms to reduce the aggregate cost of meeting the EU quota, which is the reason why milk quota transfers were allowed in the EU after 1987. Under tradeable dairy quotas, the structural change was already initiated, while under non-tradeable quota structural change was more or less braked by policy makers. Secondly, in France, in the dairy market, contracts replaced quotas in some ways. Indeed, dairies made agreements with farms to set the amount of milk to deliver and the price, depending on farms milk quality. After 2015, the dairies set the amount of milk to deliver depending on the demand but especially on past quotas. So, this is a kind of quota set by the dairies. The question is: Do these dairies agreements are a new form of quota constraint? If yes, what is its impact on French dairy farms competitiveness? Thirdly, without quotas, we may see major adjustments in all EU, where milk production could move towards EU regions having a comparative advantage in producing milk. This shift could happen both within the EU as well as outside the EU. The net effects will determine the evolving position of European milk producers in the global market. The role of efficiency and the productive capacity of farmers will be very crucial in this competition.

- As the role of efficiency and productive capacity of farmers will be crucial in the EU and world competition, it is important to evaluate their investment capacity. Identify farms which over- or under-invest and understand the determinants of their behaviour should help policy makers or stakeholders to improve farm management. It is however important to underline that this type of analyses should include social and wellbeing consideration because all investments are not targeted to improve the short-term productivity, but sometimes to improve labour conditions and farmers' wellbeing. So, the remaining questions are: Did farms over- invest or under-invest after 2015 and quota removal? What are the determinants of their investments? Several reasons could explain the fact that a farm overinvests, such as dairy quota, business taxation, spatial effects, etc. Documenting the sources of overinvestment/underinvestment could be helpful for stakeholders and policy makers. Linked to chapter 4, which studied the role of social interactions, another question is: Do farmers' interactions allow improve and optimize their investment choices? This analysis could be done by identifying farm's optimal investment path in capital assets, using the model used in chapter 2, and comparing with their actual investment. This would allow assess the direction and the deviation from the optimal investment, as done by Skevas et al. (2018).

- In chapter 3, we directly evaluated the impact of spatial spillovers on farm investment spike. However, thanks to chapter 2 and 3, we know that adjustment cost and managerial performance play a role in farm investment behaviour. One of the next question is: Do spatial effects participate in reducing adjustment costs and increasing farm performance? In other words, does farmers' communication with each other participate to reduce adjustment costs or increase performance in the neighbourhood or in a specific network? Again, documenting this pattern could help stakeholders and policy makers to find appropriate measures to improve farmers' skills.

- In chapter 3, we attempted to explain farm investment spikes, but the consequences of farm investment decisions on farm sustainability, farm resilience and farm performance have not been carried out, and could be focused on. This question deserves a long-term analysis as investment spikes represent a long-term investment.

- It could be interesting to study the impact of extension services such as the ones provided by machinery seller, bank advisors, and shared machinery cooperatives, on the probability to adopt an innovation or on investment. Two assumptions can be made: either extension services allow reaching the optimal investment path, thanks to the advice, or, on the opposite, these services give farms incentive to over-invest more than they need. To answer this question, one idea could be to build the spatial weight matrix based on the relative economic distance matrix defined by Elhorst and Halleck Vega (2017) or on the social economic distance defined by Conley and Topa (2002).

- Another type of determinant of farm investment behaviour is the role played by CAP direct subsidies. Indeed, subsidies can allow farms increasing their revenue, participating to reduce farm uncertainty and risk and so giving incentive to invest. Some studies show that subsidies could give incentives to invest depending on the subsidies types. For example, Vercammen (2007) shows that even in the absence of risk aversion, a direct payment may stimulate farm investment and that the direct payment raises the expected value of marginal investment because it reduces the risk of bankruptcy over the farmer's operating time horizon. However, we do not account for the role of subsidies on farm investment behaviour in this thesis, while in our case study, dairy farms received different types of subsidies such as the decoupled Single Farm Payments (SFP), DPI ("Déduction fiscale Pour Investissement"), which is a tax deduction for investment, DPA ("Déduction fiscale Pour Aléas"), which is a tax deduction for unforeseen circumstances, or subsidies from agro-environmental schemes (AES).

The SFP was introduced by the so-called Fischler (2003) reform of the CAP, to meet the growing demand for food consumption and became a policy instrument to support food production. Over time, the CAP was adapting to new forms of production, markets and structures, thus creating new environmental commitments. Moreover, even if the SFP was decoupled from the production, it still represented an additional income for many farmers, which participated to reduce the risk of bankruptcy. The tax deduction for investment (DPI) and the tax deduction for unforeseen circumstances (DPA) are two mechanisms in France that allow to deduce each year an amount from the farm financial results, that must be used within 7 years (for the DPI) or 10 years (for the DPA). DPI is an amount that is deducted from tax revenue, to facilitate farm investment. It can be used i) for the acquisition and production of stocks of products or animals. So, it is possible to re-affect the tax deduction on the increase of stock. As a result, DPI is particularly interesting for farmers (in case of an increase of livestock, for example); ii) for the acquisition of membership shares in agricultural cooperatives (i.e. membership shares of cooperatives sharing agricultural machinery). DPA is an amount that is deducted from tax revenue to help protect farms from unforeseen circumstances. This investment needs to be made in a year in which the financial results are very high. This amount plays an insurance role to prevent from unforeseen circumstances. DPA can serve to pay insurance contributions; to purchase insurance franchises; to prevent from the occurrence of uninsured risks of climatic, natural or health origin. The idea is that the farmer builds his/her own insurance, and the legislation gives him/her a tax relief. Likewise, the AES of the CAP provide payments to voluntary farmers who implement agri-environmental measures.

Indeed, including these types of subsidies in chapter 3 could affect the results. For example, the effect of adjustment costs and/or productivity of capital could be over-estimated in our case study. Likewise, including AES subsidies in the estimation strategy in chapter 4 could affect the results. For example, if an AES is contracted at a local point in space, in the Ille-et-Vilaine sub-region, the neighbourhood effects could be over-estimated. Unfortunately, because of the lack of precise data on subsidies, we were not able to include this dimension in the modelling strategy.

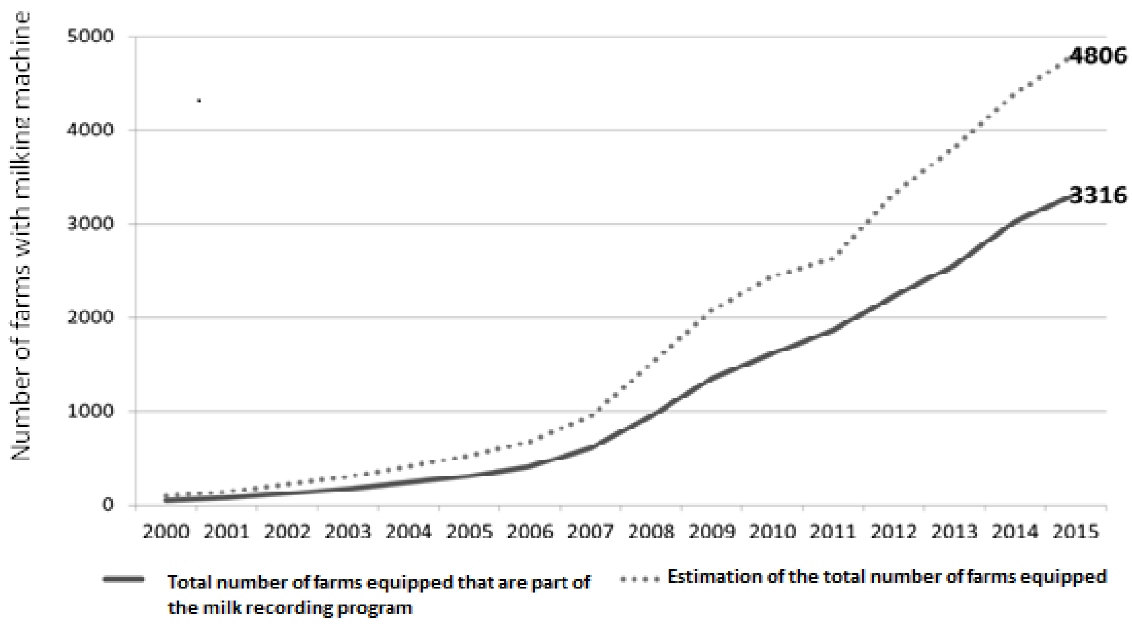
- As described in chapter 1, many innovations have been adopted over time in the dairy farm sector, since the beginning of the twentieth century. However, one of the main recent innovations, which is spreading up among farmers, in France and in Europe as well, is the milking robot. The adoption of the milking machine has increased more and more (figure 5.1).

  Among dairy farms member of the milk recording program[18], the evolution of the number of farms having a milking robot has grown almost exponentially since the beginning of the 2000s, with however a slight inflection in 2009 due to the milk crisis, in France. In 2015, despite a 10% growth compared to the previous year, a slowdown is also visible (2014 growth was 15%). At the end of 2015, 3,316 farms were equipped, 10 times more than 2005 and twice more than 2010[19].

[18] The milk recording program in France is an organization in charge of controlling and measuring the quantity and quality of milk produced by cows during their lactations.

[19] http://idele.fr/rss/publication/idelesolr/recommends/robots-de-traite-le-deploiement-continue.html

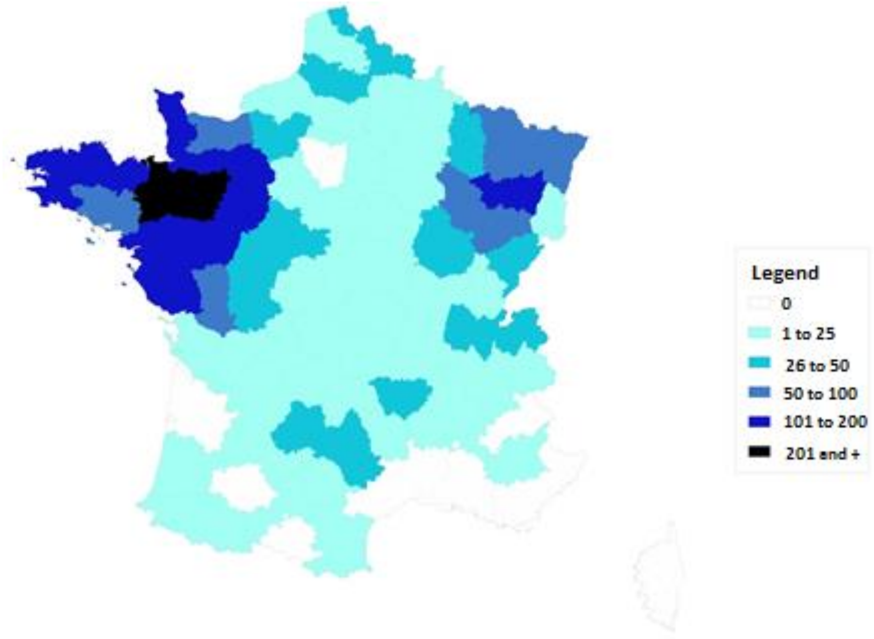
FIGURE 5.1 : Number of farms equipped with a milking robot



Source: Institut de l'Elevage (Idele)

Almost all French administrative sub-regions (NUTS3) are now concerned by the presence of at least one farm equipped with a robot. Obviously, the western part of France is more concerned (Ille- et-Vilaine sub-region leading), but the eastern dairy sub-regions are also increasingly equipped (figure 5.2). According to statistics published by the IFR (International Federation of Robotics), in 2012, 2013 and 2014, respectively 4,750, 4,790 and 5,180 milking robots have been sold worldwide. For these 3 years, France represents respectively 19, 13 and 14% of the world market.

FIGURE 5. 2 : Number of farms equipped with a milking robot, per French sub-region



Source: Institut de l'Elevage (Idele)

Many reasons explain the growing rate of adoption of milking robot; i) the quality of milking robots is better than before; ii) this allows a better oversight of the health of cows thanks to improved monitoring methods; iii) this allows farmers to more free time; v) peer influences from neighbourhood of from networks; vi) this allows to remain competitive in the future (knowing that the other EU countries such as the Netherlands adopt more and more the milking robot since 2008). Documenting the benefit of milking robot and its diffusion among French farmers, could help policy makers to draw policy and stakeholders to adapt their strategies. Moreover, from a policy view point, other studies on investment and especially on the adoption of innovations should better identify pioneers, and should document their characteristics. Identifying pioneers could be crucial for policy makers and stakeholders in order to spread up the adoption of innovating investments.

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Appendices

A.1 Theoretical framework of farms' investment with adjustment costs, releasing the assumption of constant milk price[20]

The theoretical framework assumes that dairy farmers are risk neutral and maximise the expected net present value of their profits in period *t* over an infinite horizon (eq. 1):

$$Max\ E_{it}\ \left\{\sum_{t=0}^{\infty}\frac{1}{1+r_t}\pi_{it}\{K_{it}, I_{it}, X_{it}\}\right\} \tag{1}$$

on K_{it}, I_{it}, X_{it}

subject to

$$K_{it} = (1-\delta)K_{it-1} + I_{it} \tag{2}$$

$$\pi_{it}\{K_{it}, I_{it}, X_{it}\} \geq 0 \tag{3}$$

where subscript *i* denotes the *i*-th farm and subscript *t* denotes the *t*-the period; farm capital K_t is a stock variable and investment I_t is a flow variable; X_t is the level of variable inputs used on the farm; $\frac{1}{1+r_t}$ is the discount factor; δ is the depreciation rate; E_t is the expectation operator conditional on information available to the farmer at the start of period *t*, expectations being taken over future prices and technologies (Bond and Meghir, 1994).

Equation (2) represents capital accumulation, in the sense that the current capital stock consists of last year's capital stock, adjusted for depreciation at rate δ, plus current investment. Equation (3) is a non-negativity constraint that ensures that the farm profit is positive in each period.

Following this, the Euler equation defining the optimal investment path can be derived (eq. 4). We assume here rational expectations (Muth, 1961), implying that the expected value in period *t*-1 is equal to the value in period *t* corrected with an error term:

$$E_{it}\left\{\frac{\partial\pi_{it}}{\partial I_{it}}\right\} - (1-\delta)\frac{1}{(l+r_t)}E_{it}\left\{\frac{\partial\pi_{it+1}}{\partial I_{it+1}}\right\} + E_{it}\left\{\frac{\partial\pi_{it}}{\partial K_{it}}\right\} = \varepsilon_{it+1} \tag{4}$$

[20] This framework has been developed with Laure Latruffe and Aude Ridier.

where ε_{t+1} is an error term that is assumed to be uncorrelated with the explanatory variables.

For the i-th farm in period t, denote profit by

$$\pi_{it} = p_{it}\, y_{it} - w_{it}\, X_{it} - q_{it}\, I_{it} - p_{it}\, C_{it} \tag{5}$$

where $p_{it} \in \mathbb{R}_+$ is the price of output y_{it}, $w_{it} \in \mathbb{R}_+^m$ are the prices of the variable inputs X_{it}, and $q_{it} \in \mathbb{R}_+$ is the price of investment I_{it} and C_{it} is adjustment costs.

The production function for the agricultural output is specified as Cobb-Douglas:

$$y_{it} = {K_{it}}^{\alpha} {X_{it}}^{1-\alpha} \tag{6}$$

where α is the elasticity of output with respect to capital such that $0 < \alpha < 1$.

Adjustment costs are assumed to be increasing and convex, and specified as a quadratic function of the investment to capital ratio:

$$C_{it} = \frac{b}{2}\left(\frac{I_{it}}{K_{it}} - d\right)^2 K_{it} \tag{7}$$

where b and d are parameters such that $b>0$ and $d>0$.

The first-order necessary conditions for the choice of capital K_{it}, and investment I_{it} are

$$\frac{\partial y_{it}}{\partial K_{it}} = \alpha \frac{y_{it}}{K_{it}} \tag{8a}$$

$$\frac{\partial C_{it}}{\partial K_{it}} = \frac{b}{2}\left[-\left(\frac{I_{it}}{K_{it}}\right)^2 + d^2\right] \tag{8b}$$

$$\frac{\partial C_{it}}{\partial I_{it}} = b\left(\frac{I_{it}}{K_{it}} - d\right). \tag{8c}$$

Combining equation (4) with equations (8a), (8b) and (8c), and assuming that the interest and the price of investment (but not the price of output) are constant through time and across firms (as followed by Bond and Meghir (1994) and Benjamin Phimister (1997), we obtain the following Euler equation with full specifications:

$$p_{it}\alpha \frac{y_{it}}{K_{it}} + p_{it}\frac{b}{2}\left(\frac{I_{it}}{K_{it}}\right)^2 + p_{it}bd - p_{it}\frac{b}{2}d^2 + (-bd)\,(1-\delta)\frac{1}{(l+r_t)}p_{it+1} +$$

$$(1-\delta)\frac{1}{(l+r_t)}b\frac{I_{it+1}}{K_{it+1}}p_{it+1} + (1-\delta)\frac{1}{(l+r_t)}q_{it+1} - p_{it}b\frac{I_{it}}{K_{it}} - q_{it} = \varepsilon_{it+1} \tag{9}$$

which can be rewritten as:

$$\frac{I_{it+1}}{K_{it+1}} = \beta_0 + \beta_1 \frac{p_{it}}{p_{it+1}} \left(\frac{y_{it}}{K_{it}}\right) + \beta_2 \frac{p_{it}}{p_{it+1}} \left(\frac{I_{it}}{K_{it}}\right) + \beta_3 \frac{p_{it}}{p_{it+1}} \left(\frac{I_{it}}{K_{it}}\right)^2 + \beta_4 \frac{p_{it}}{p_{it+1}} + \beta_5 \frac{1}{p_{it+1}} + \varepsilon_{it+1} \quad (10)$$

where

$$\beta_0 = d \quad (11)$$

$$\beta_1 = -\frac{(1+r_t)}{(1-\delta)} \frac{\alpha}{b} \quad (12)$$

$$\beta_2 = \frac{(1+r_t)}{(1-\delta)} \quad (13)$$

$$\beta_3 = -\frac{1}{2} \frac{(1+r_t)}{(1-\delta)} \quad (14)$$

$$\beta_4 = -\left(d - \frac{d^2}{2}\right) \frac{(1+r_t)}{(1-\delta)} \quad (15)$$

$$\beta_5 = -\frac{q_{it+1}}{b} + \frac{q_{it}}{b} \frac{(1+r_t)}{(1-\delta)} \quad (16)$$

Equation (13) shows that the coefficient on the lagged investment ratio (β_2) is expected to be positive, indicating that farmers tend to smooth their investment over time in order to keep adjustment costs low. This effect is higher when output price tends to increase.

Equation (12) shows that the coefficient of the output term (β_1) is expected to be negative, indicating that, when the productivity of capital is high, investment will be postponed in later periods than the next period in order to keep adjustment costs low. This effect is higher when output price tends to decrease.

Equation (14) shows that the coefficient of the squared lagged investment ratio (β_3) representing the marginal cost of having a higher level of capital in the profit function is expected to be negative. This effect is higher when output price tends to decrease, indicating that the cost of having a higher level of capital is higher when the output price decreases.

Equation (15) shows that the coefficient of the output price ratio (β_4) is expected to be: (i) negative when the adjustment costs parameter verifies $0<b<2$; (ii) zero when $d=2$; (iii) positive when $d>2$. In the case where $\beta_4 < 0$, an increase of output price creates an incentive to invest.

Finally, equation (16) shows that the coefficient of the inverse of output price in t+1 (β_5) is expected to be negative, indicating that an increase in output price in t+1 creates incentives to invest in t+1.

A.2 Theoretical framework of farms' investment with adjustment costs, with performance included explicitly[21]

The theoretical framework assumes that dairy farmers are risk neutral and maximise the expected net present value of their profits π at time *t* over an infinite horizon (eq. 1):

$$Max\ E_t \left\{ \sum_{t=0}^{\infty} \frac{1}{1+r_t} \pi_t\{K_t, I_t, X_t\} \right\} \quad (1)$$

on K_t, I_t, X_t

subject to

$$K_t = (1-\delta)K_{t-1} + I_t \quad (2)$$

$$\pi_t\{K_t, I_t, X_t\} \geq 0 \quad (3)$$

where farm capital K_t is a stock variable and investment I_t is a flow variable; X_t is the level of variable inputs used on the farm; $\frac{1}{1+r_t}$ is the discount factor; δ is the depreciation rate; E_t is the expectation operator conditional on information available to the farmer at the start of period *t*, expectations being taken over future prices and technologies (Bond and Meghir, 1994). For simplification, the farm subscript *i* is dropped from all variables.

Equation (2) represents capital accumulation, in the sense that the current capital stock consists of last year's capital stock, adjusted for depreciation at rate δ, plus current investment. Equation (3) is a non-negativity constraint that ensures that the farm profit is positive in each period.

The Lagrangian function can be written as follows:

$$L = E_t\{\sum_{t=0}^{\infty} \beta_t \pi_t\{K_t, I_t, X_t\}\} + \cdots + \lambda_t[I_t - K_t + (1-\delta)K_{t-1}] + \lambda_{t+1}[I_{t+1} - K_{t+1} + (1-\delta)K_t] + \cdots + \mu_t[\pi_t\{K_t, I_t, X_t\}] + \mu_{t+1}[\pi_{t+1}\{K_{t+1}, I_{t+1}, X_{t+1}\}] \quad (4)$$

where λ_t and μ_t are the Lagrangian multipliers associated with constraints (2) and (3) respectively.

The first order conditions for investment I_t and capital K_t respectively are as follows:

$$\frac{\partial L}{\partial I_t} = E_t\left\{(\beta_t + \mu_t)\frac{\partial \pi_t}{\partial I_t}\right\} + \lambda_t = 0 \quad (5)$$

[21] This framework has been developed with Laure Latruffe and Aude Ridier.

$$\frac{\partial L}{\partial K_t} = E_t\left\{\left(\beta_t + \mu_t\right)\frac{\partial \pi_t}{\partial K_t}\right\} - \lambda_t + \lambda_{t+1}(1-\delta) = 0 \tag{6}$$

Combining these two first order conditions yields:

$$E_t\left\{\left(\beta_t + \mu_t\right)\frac{\partial \pi_t}{\partial I_t}\right\} + E_t\left\{\left(\beta_t + \mu_t\right)\frac{\partial \pi_t}{\partial K_t}\right\} - (1-\delta)E_t\left\{\left(\beta_{t+1} + \mu_{t+1}\right)\frac{\partial \pi_{t+1}}{\partial I_{t+1}}\right\} = 0 \tag{7}$$

Following this, the Euler equation defining the optimal investment path can be derived (eq. 8). We assume here rational expectations (Muth, 1961), implying that the expected value in period *t-1* is equal to the value in period *t* corrected with an error term:

$$E_t\left\{\frac{\partial \pi_t}{\partial I_t}\right\} - (1-\delta)\frac{\left(\beta_{t+1}+\mu_{t+1}\right)}{\left(\beta_t+\mu_t\right)}E_t\left\{\frac{\partial \pi_{t+1}}{\partial I_{t+1}}\right\} + E_t\left\{\frac{\partial \pi_t}{\partial K_t}\right\} = \varepsilon_{t+1} \tag{8}$$

where ε_{t+1} is an error term that is assumed to be uncorrelated with the explanatory variables.

The profit function in period *t* is specified as follows:

$$\pi_t\{K_t, I_t, X_t\} = p_t Y_t - C_t - w_t X_t - p_t^I I_t \tag{9}$$

where p_t is the output price; Y_t is the output produced; C_t is adjustment costs; w_t is the variable input price and p_t^I is the investment price.

Our contribution is to model the link between performance and investment decisions. For this, we assume that the output not only depends on the production factors (fixed and variable inputs), but also on a performance variable designated u_t (eq. 10), which could be viewed as the farmer's managerial ability (Galanopoulos et al., 2006; Ondersteijn et al., 2003; Solano et al., 2006)

$$Y_t = f(K_t, X_t, u_t) \tag{10}$$

where u_t is the performance of the farm.

The production function f is assumed to be quadratic and to increase with performance.

Our further contribution is that assume that performance depends on capital stock, capturing size effects (eq.11). However, no specific assumption is made about the sign of the first derivative of the performance function g with respect to capital; that is, about the sign of scalar b in equation (12). The derivative may be either negative or positive. If negative, it means that farmers operating farms with larger capital would have a lower performance than farmers operating farms with smaller capital. If positive, it indicates that farmers with farms with larger capital would have a higher performance than those operating farms with smaller capital. It is assumed that the effect of capital size on performance depends on the level of performance itself (eq. 12) so that the effect is amplified at high levels of performance.

$$u_t = g(K_t) \tag{11}$$

$$\frac{\partial g(K_t)}{\partial K_t} = bu_t \tag{12}$$

The first derivatives of the production function with respect to capital and to performance are as follows (eq. 13 and 14):

$$\frac{\partial f(Y_t)}{\partial K_t} = \alpha_0 + \alpha_1 K_t + \alpha_2 X_t + \alpha_3 u_t \quad > 0 \tag{13}$$

$$\frac{\partial f(Y_t)}{\partial u_t} = a > 0 \tag{14}$$

Equation (13) shows that the derivative with respect to capital is assumed to be positive, meaning that output increases when capital increases, but no assumption is made on the sign of the parameters $\alpha_0, \alpha_1, \alpha_2,$ and α_3. Equation (14) represents the intuitive idea that, the higher the farmer's performance, the higher the output produced.

As is standard in the literature, the adjustment costs incurred by farms are assumed to be quadratic and to depend on K_t and I_t through a function h (eq. 15), whose derivative with respect to investment increases with investment (eq. 16) and whose derivative with respect to capital depends on investment squared (eq. 17):

$$C_t = h(K_t, I_t) \tag{15}$$

$$\frac{\partial h(K_t,I_t)}{\partial I_t} = \theta_0 + \theta_1 I_t \qquad \text{with } \theta_1 > 0 \tag{16}$$

$$\frac{\partial h(K_t,I_t)}{\partial K_t} = \gamma_0 + \gamma_1 {I_t}^2 \tag{17}$$

Using equations (9), (10) and (15), the Euler equation (8) can then be rewritten as follows (eq. 18):

$$\frac{\partial \pi_t}{\partial C_t}\frac{\partial C_t}{\partial I_t} - p_t^I - (1-\delta)\frac{(\beta_{t+1}+\mu_{t+1})}{(\beta_t+\mu_t)}\left(\frac{\partial \pi_{t+1}}{\partial C_{t+1}}\frac{\partial C_{t+1}}{\partial I_{t+1}} - p_{t+1}^I\right) + \frac{\partial \pi_t}{\partial Y_t}\frac{\partial Y_t}{\partial K_t} - \frac{\partial \pi_t}{\partial C_t}\frac{\partial C_t}{\partial K_t} = \varepsilon_{t+1} \tag{18}$$

Furthermore, using equations (12), (13), (14), (16), (17), it can be rewritten as (eq. 19):

$$-(\theta_0+\theta_1 I_t)-p_t^I-(1-\delta)\frac{(\beta_{t+1}+\mu_{t+1})}{(\beta_t+\mu_t)}(-(\theta_0+\theta_1 I_{t+1})-p_{t+1}^I)+p_t(\alpha_0+\alpha_1 K_t+\alpha_2 X_t+\alpha_3 u_t)-(\gamma_0+\gamma_1 {I_t}^2)=\varepsilon_{t+1} \quad (19)$$

Assuming that the price of investment (p_t^I) is constant across farms and years, the final model is (eq. 20):

$$I_{t+1}=\vartheta_0+\vartheta_1 I_t+\vartheta_2 {I_t}^2+\vartheta_3 u_t p_t+\vartheta_4 X_t p_t+\vartheta_5 K_t p_t+\vartheta_6 p_t+\varepsilon_{t+1} \quad (20)$$

with:

$$\vartheta_1=\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (21)$$

$$\vartheta_2=\frac{\gamma_1}{\theta_1}\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (22)$$

$$\vartheta_3=-\frac{\alpha_3}{\theta_1}\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (23)$$

$$\vartheta_4=-\frac{\alpha_2}{\theta_1}\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (24)$$

$$\vartheta_5=-\frac{\alpha_1}{\theta_1}\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (25)$$

$$\vartheta_6=-\frac{\alpha_0}{\theta_1}\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})} \quad (26)$$

Equation (21) shows that ϑ_1 is positive, and hence a positive impact of I_t on I_{t+1} is expected (eq. 20). As θ_1 and $\frac{(\beta_t+\mu_t)}{(1-\delta)(\beta_{t+1}+\mu_{t+1})}$ are assumed to be positive, the direction of the impact of ${I_t}^2$ on I_{t+1} (i.e. the sign of ϑ_2, eq. 22) gives an indication of the sign of γ_1 that is to say on the shape of the adjustment cost function (eq. 17). The sign of ϑ_3 (eq. 23), related to the effect of $u_t p_t$ on I_{t+1}, gives an indication of the sign of α_3 that is the direction of the impact of performance u_t on the marginal productivity of K_t (eq. 13). The sign of ϑ_4 (equation 24), related to the effect of $X_t p_t$ on I_{t+1}, gives an indication of the sign of α_2 namely the effect of X_t on the marginal productivity of K_t. The direction of the impact of $K_t p_t$ on I_{t+1} (ϑ_5, eq. 25) gives an indication of the sign of α_1 namely on the effect of K_t on the marginal productivity of K_t.

UNIVERSITE BRETAGNE LOIRE / ECONOMIE ET GESTION

AGRO CAMPUS OUEST

Titre : COMPORTEMENT D'INVESTISSEMENT DES EXPLOITATIONS LAITIERES FRANÇAISES : LE CAS DE LA BRETAGNE

Mots clés : investissement des exploitations agricoles, politique agricole, quota, performance, modèle de coût d'ajustement, effet de voisinage, interaction sociale, secteur laitier, France.

Résumé : L'investissement et l'innovation jouent un rôle important dans le secteur agricole, permettant aux exploitations de s'adapter aux changements de politiques et aux conditions du marché. Au cours des dernières décennies, les exploitations agricoles de l'Union européenne (UE) ont été confrontées à des changements substantiels à travers la politique agricole commune (PAC). C'est notamment le cas du secteur laitier, qui a vu la fin du régime de quotas laitiers et également vu une volatilité accrue des prix. De tels changements pourraient affecter la productivité et l'efficacité des exploitations agricoles, la compétitivité du secteur laitier et les changements structurels. Comprendre les mécanismes sous-jacents au comportement d'investissement des exploitations pourrait permettre d'identifier les principaux facteurs qui influent sur les tendances observées. Cela pourrait aider à anticiper les futurs changements structurels, prévoir les besoins des exploitations et aider les décideurs publics et les autres acteurs du secteur agricole à adapter leurs politiques. La thèse contribue à cet objectif en analysant pour les exploitations laitières d'une sous-région de Bretagne (Ille-et-Vilaine) en France, (i) l'impact de la suppression du quota laitier sur les décisions d'investissement des agriculteurs et l'hétérogénéité de leurs réactions (ii) le lien entre la performance agricole et les décisions d'investissement des agriculteurs, (iii) le rôle des interactions sociales liées aux effets de voisinage sur la décision d'investissement des agriculteurs.

Les résultats montrent que la fin de la politique des quotas laitiers a incité les agriculteurs à investir, ce qui a favorisé les fermes laitières plus grandes, à plus forte intensité de capital et plus spécialisées. En outre, la thèse souligne la nécessité de prendre en compte l'hétérogénéité des agriculteurs dans la modélisation du comportement des investissements. Cela permet de révéler des stratégies différenciées et peut aider à concevoir des politiques ciblées visant à encourager les investissements, en particulier dans le contexte de l'élimination du système de quotas. Enfin, la thèse prouve que les agriculteurs prennent en compte les décisions de leurs voisins lorsqu'ils prennent de grandes décisions d'investissement. Cependant, bien que les effets de voisinage soient un facteur multiplicateur positif dans les grandes décisions d'investissement des exploitations agricoles, les politiques devraient également prendre en compte le fait que les exploitations font face à des coûts d'ajustement lors de la mise en œuvre de projets d'investissement.

Title: INVESTMENT DECISIONS OF FRENCH DAIRY FARMS: THE CASE OF BRITTANY

Keywords: farm investment, agricultural policy, quota, performance, adjustment cost model, spatial neighbourhood effects, social interaction, dairy sector, France.

Abstract : Investment and innovation play an important role in the agricultural sector, allowing farms to adapt to policy changes and market condition changes. In the last decades, farms in the European Union (EU) have faced substantial changes in the Common Agricultural Policy (CAP). This is particularly the case of the dairy sector, which has seen the end of milk quota regime and increased price volatility. Such changes could affect farm productivity and efficiency, the dairy sector's competitiveness and structural change. Understanding the mechanisms underlying farms' investment behaviour could allow identifying key drivers that influence the observed trends. This could help anticipate future structural changes, predict farms' needs and help policy makers and other stakeholders in farming to adapt their policy. The thesis contributes to this objective by analysing for dairy farms in a sub-region of Brittany (Ille-et-Vilaine) in France, (i) the impact of the termination of the milk quota on farmers' investment decisions and the heterogeneity of farm investment behaviour, (ii) the link between farm performance and farmers' investment decisions, (iii) the role of social interactions related to neighbourhood effects on farmers' investment decision.

Findings show that the termination of the dairy quota policy increased farmers' incentive to invest, contributing to the trend towards larger, more capital intensive and more specialised dairy farms. In addition, the thesis underlines the need to take into account farmers' heterogeneity in modelling investment behaviour. Doing so allows differentiated strategies to be revealed and can help design targeted policies aiming at encouraging investment, in particular in the context of quota system elimination. Finally, the thesis provides evidence that farmers account for their neighbours' decisions when they make large investment decisions. However, although neighbourhood effects are a positive multiplier in farms' large investment decisions, policies should also take into account that farms face adjustment costs when implementing investment projects.