Title	Dairy and grassland economics in an era of possible expansion
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Publication Date	2015-10-14
Item record	http://hdl.handle.net/10379/5317

Dairy and grassland economics in an era of possible expansion

A thesis submitted in fulfilment of the degree of

Doctor of Philosophy

By

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Description of Thesis

The research contained in this thesis focuses on the efficiency and the Total Factor Productivity (TFP) which is associated with the dairy enterprise of Specialist Dairy farms. The approach uses econometric methods to generate its measures. Special emphasis is given to the effect of milk quota policy on these measures, and this is timely given the abolition of milk quotas as of April 2015. The objectives of this thesis are enumerated below;

1. to establish long term trends in productivity measures using NFS data,
2. to quantify and decompose TFP for Irish dairy farms,
3. to examine the distributional effects of milk quota policy, and
4. to assess the effect of grass utilisation on dairy efficiency.

The thesis opens with an in-depth view of quota policy, followed by a more general view of the policy environment that is relevant to dairy farms. Further context is provided with a statistical analysis of long term structural developments in the dairy sector. The analysis of TFP is data intensive, so a detailed discussion of how this requirement is satisfied precedes the analytical chapters. The resulting data are then used to achieve a long-run analysis of dairy productivity. The chapters progress from this long-run Irish analysis to a shorter cross-country comparison which serves as a natural experiment, and finally to a wider selection of countries in an effort to assess the effect grass utilisation has on various forms of efficiency.

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Glossary

AE	Allocative efficiency
CAP	Common Agricultural Policy
CE	Cost efficiency
CMO	Common Market Organisation
CO_2	Carbon Di-Oxide
cpl	Cent per litre
DAFM	Department of Agriculture, Food, and the Marine
DEA	Data Envelopment Analysis
DC	Direct costs
EC	European Community
EEA	European Economic Area
EEC	European Economic Community
EPA	Environmental Protection Agency (of Ireland)
EU	European Union
FADN	Farm Accountancy Data Network
FWMS	Farm Waste Management Scheme
Gg	Giga-grams
GHG	Greenhouse gases
LU	Livestock unit
ML	Maximum likelihood
NAP	National Action Plan
ND	Nitrates directive
NUIG	National University of Ireland, Galway
SF	Stochastic frontier
SFA	Stochastic frontier analysis
TE	Technical efficiency
UAA	Utilisable agricultural area
UK	United Kingdom
WFD	Water framework directive
WTO	World trade organisation

IE	Ireland
NI	Northern Ireland
ppl	Pence per litre
MMB	Milk Marketing Board

Statement

I declare that the contents of this thesis were entirely my own work.

Signed

Patrick Gillespie

Patrick R. Gillespie

13 October 2015

Acknowledgement

This work would not be possible without the financial support of Teagasc and of the Multi-sward European Union framework project. I thank my supervisors at the National University of Ireland, Galway and at Teagasc for the valuable insights they provided along the way. My research has also benefitted from the commentary of colleagues and fellow students in these two fine institutions.

I owe a great debt of gratitude to my own parents and to my wife’s parents for the strong support they have shown me. I hope to be proven worthy of their confidence some day.

Above all, it was my wife, Noreen, that made this dream possible. I address these last few words to her. *Thank you for your kindness, your patience, and your love. In truth, this is as much your accomplishment as it is mine.*

Chapter 1 Introduction

1.1 Introduction

There are many reasons to study milk marketing quota (hereafter referred to simply as quota or milk quota). It has been an enduring feature of the Common Agricultural Policy (CAP) for over 30 years. It was an effective policy in that it raised dairy output prices within the European Union (EU) whilst simultaneously limiting adverse effects on the CAP budget related to the oversupply of dairy products. However, there may also have been other effects from this supply control, e.g. altering structural change, the distribution of farm income amongst dairy farms, and the environmental intensity of dairy production. In this year in which the quota policy has come to an end, there is already a suite of models predicting large expansions in dairy output; in Ireland there are some reports of dairy farms undertaking expansion even in the last year of the quota policy, and hence willingly paying fines on over-quota production. Clearly, quota has been a important policy instrument during its lifetime, and its removal portends major changes for the dairy sector.

The interest which farmers, industry groups, and government have in an economic analysis of quota is obvious. However, the removal of quota also presents an opportunity to explore the nature of supply constraints themselves as well as production under these conditions. Given the policy focus on competitiveness which has accompanied the liberalisation of the CAP, and the end of the era of quotas, productivity and efficiency analyses of the dairy sector are both timely and justified.

The structure of the chapter is as follows. Section 1.2 motivates the need to understand milk quota, gives a brief evolution of the policy, and cites a few prominent works from the literature. Section 1.3 does the same for the concepts of productivity and efficiency. Section 1.4 reviews the outputs from this research, inclusive of a major advancement of the availability of farm-level data in Ireland. Section 1.5 outlines the structure of the remainder of the thesis.

1.2 The need to understand quota

This section provides additional motivation for an analysis of milk quota—particularly as it pertains to Ireland—and also provides a brief history of the policy's development. This section also examines some of the literature concerning milk quota specifically.

The need to understand the impact of milk quota is felt most acutely in Ireland. Bovine production systems dominate here, and dairy in particular has enjoyed a long ascendancy in terms of relative importance (Donnellan, 2000). Specialist dairy farms were the most profitable of all farm systems in Ireland on a per hectare basis in 2012; the mean family farm income per hectare on dairy farms was €887 as compared to the corresponding figure of €541 for all farms.

Dairy farms typically derive a larger share of their profits from market income than do other types of farms, and a larger proportion of dairy farms are therefore classed as 'economically viable' than is the case for other systems of farming.

Dairy farms are tightly linked with the beef industry, both because many dairy farms have a substantial beef enterprise on them, and because roughly 80 percent of dairy calves are sold into the beef sector every year, thus providing a key input for that system.

The dairy industry is an important source of jobs in the rural economy by employing tens of thousands both in primary production and in the processing sector. Finally, Ireland is self-sufficient in dairy production several times over, and this makes it a larger player in the global milk trade than its small size would otherwise imply.

The development of milk marketing quota policy

To state that the dairy sector is less reliant on direct payments than other farm systems is not to say that it is fully liberalised. Most Irish dairy farms have a substantial beef enterprise, and these are no less likely to draw supports related to that commodity than more specialised beef producers. Furthermore, several market based supports are still enshrined in the CAP. Indeed, it was the market distortions initiated in Reg. 804/68 (SP OJ 1968 (1)) which provided the need for some form of policy-based production control.

The first attempt at curtailing production was a co-responsibility levy in Reg.1079/77 (OJ 131 26-5-77) in 1977; this tax was set at a level to cover the expense of disposing of excess production. Evidently, this was of minor effect (Fennel, 1987), and it was soon followed by various guarantee limits in 1981. However, it would take the introduction of quotas in 1984 with Reg. 856/84 (OJ L90, 1-4-84) before any real levelling-out of production could be said to have taken place in Ireland.

Since the introduction of milk quota there have been various adjustments to the policy. Several EU wide reductions to Member State (MS) national allocations took place in the

1980's. Quota was at first 'attached to the land', but this was relaxed as part of reforms to the CAP in 1993, and the different Member States have since allowed various amounts of freedom in quota markets. There have also been a number of increases to national quota allocations in the 1990's, around the Agenda 2000 reforms, and most recently five straight years of one or two percent increases starting in 2009.

In Ireland, quota redistribution was handled administratively until 2007/08 when a 'ring-fenced' market mechanism was put into place. Prior to this, redistribution was carried out on the basis of various restructuring schemes at prices set by the State, and with the link to the land largely maintained. Even since the establishment of a market mechanism, 30 percent of traded quota had to be made available for 'priority pools' at the statutory price, with access to this pool being reserved for classes of producers which were designated in the Irish legislation. The priority pools tended to make quota more difficult to acquire for larger, more commercial operations, and this may have adversely affected sectoral productivity and efficiency.

Other policies of consequence in the timeline include a Milk Outgoers scheme in 1986 Reg. 1336/86 (OJ L119, 8-5-86) which incentivised permanent cessation of dairy production amongst marginal producers, and several changes to intervention buying of butter and skimmed milk powders in Reg. 773/87, 774/87, 777/87 (OJ L78, 20-3-87) in 1987. Another noteworthy change was the exclusion of salted butter from any intervention buying, which was moderately consequential in Ireland and the United Kingdom (UK) as most butter produced in this region was of the salted variety.

Selected literature regarding quota and the dairy sector

Milk quota policy has generated many studies over its lifetime, and its abolition has resulted in a flurry of work as well. There are a few often cited partial equilibrium models which are of interest here.

The European Commission (2009) used a partial equilibrium modelling framework to examine the likely impact of milk quota abolition. The report's conclusions include a projection that Ireland will dramatically increase its milk production after abolition of the milk quota system and that this will be accompanied by an increase in herd size and a simultaneous decrease on the order of 4.5 per cent in agricultural income by 2020.

Bouamra-Mechemache et al. (2008) used a spatial equilibrium model to find that by 2014-2015, the market effects of abolishing quota were not very different from those of a 2 per cent gradual increase starting in 2009. In an earlier paper the authors used the results of a short-run partial equilibrium model to argue—on public welfare grounds—that reducing export refunds would be preferable when compared to milk quota expansion (Bouamra-Mechemache and Réquillart 2000).

In a separate study, Flaten (2003) took a deterministic, micro-level approach using a linear programming model to examine the effects of differing assumptions regarding price, headage payments, and quota on the usage of forage crops, herd size, and yield per cow. His work examined optimal responses to policy changes for Norwegian farms with a fixed milk quota, and it found that (at 1999 prices) a low-to-moderate yielding herd was most profitable. Furthermore, a three-cut silage system was optimal under these conditions.

Elsewhere, Wieck and Heckelei (2007) wrote an influential paper which estimated cost functions from microdata. They used the FADN data on the years 1989 to 2000 to construct a model which estimated multi-input, multi-output Symmetric Generalized McFadden cost functions. They concluded that milk output, milk yield, the degree of specialization, and farm size all have a negative relationship with marginal costs. On the other hand, grassland shares were positively correlated across regions, but grassland share was used as a proxy for remotely located farms; the authors made it clear that they did not imply any relationship between marginal costs and choice of input system. They also found that marginal costs decreased over time, but they could not connect this to differences in implementation of the milk quota regime. The authors identify avenues for further research which include the specification of more sophisticated models and using datasets which have longer time horizons to investigate determinants of structural change.

Jesse et al. (2007) conducted a case study of the Irish dairy sector. Key points included: Ireland's climate and geographic location make it ideally suited for a grass-based production system; the milk quota regime has had a negative effect on output growth and structural change in the sector; and much of the change post-quota abolition will be positive, with some estimates of output growth at around 20 percent.

Richards (1996) carried out a study using Canadian data. It found that the existence of a quota system created over-investment in cattle and family labour, which slowed total factor productivity growth and competitiveness. Interestingly, he also found that simulations under different policy regimes showed that productivity growth was 4 per cent lower with quotas relative to a policy which supported the milk price, but did not introduce a quota license requirement. He also concluded that creating a national quota system for Canada (i.e. making the quota transferable across regions) had no effect with regard to TFP.

Kumbhakar et al. (2008) used panel data of Norwegian dairy farms over the time period 1976 to 2005 to examine the effects of the milk quota regime on the rate of output growth. The authors specified a growth rate model to control for farm-specific effects and to help with theoretical consistency (i.e. non-negativity constraints on input elasticities). The time period covers three quota schemes: pre-quota; restrictive quota implementation; and a flexible quota scheme. They conclude that the quota system slowed output growth and technical change, and that these measures would improve if the quota regime were liberalised.

These latter two studies provide examples of the interactions of the quota system with the productivity and efficiency literature. The next section gives the motivations for examining the productivity and efficiency of a production system.

1.3 The need to study productivity and efficiency

This section gives the rationale for undertaking studies of productivity and efficiency. A discussion of the applicable definitions of efficiency ensue, before some background on modern productivity analysis is given. Finally, the section examines some of the literature on productivity and efficiency measurement in agriculture in different regions of the world to give some context to more specific analyses later on in the thesis.

Since one of the main inputs in agricultural production is land, and since the quantity of land is essentially fixed, it is only the increasing of agricultural productivity which has allowed food systems to accommodate a population explosion which occurred since

Malthus's dire predictions.(Kögel and Prskawetz, 2001). To the extent that studies of productivity may perpetuate further expansions of the food supply , these works are immensely valuable.

Productivity studies of Irish dairying are very timely in a more specific sense. Several studies of the supply response to the abolition of milk quota forecast an expansion of dairy output in Ireland. Since dairying is a subset of agricultural production, the argument from the preceding paragraph also applies, albeit with a proviso.

Although agricultural land is fixed, the land input available to the dairy sector may be expanded. The chief mechanism one might expect this expansion to occur through in Ireland is via substitution away from beef production (Läpple and Hennessy, 2012). Productivity studies then measure not only the ability to expand production in a neutral sense, but they also give a sense of the degree to which it is necessary to substitute away from other systems.

In addition to the effects quota abolition may have on the prevalence and intensity of competing farm systems, quota abolition is forecast to affect the international distribution of milk production across the EU. Most studies project a comparative advantage for northern coastal regions of the EU.

Finally, the abolition of quota and other reforms of the CAP are set to usher in an era of heightened price volatility. This has been visible in the data since 2007. In this new production environment farm efficiency-particularly in relation to costs-are seen as a viable strategy for the survival of smaller farms such as are prevalent in Ireland.

These arguments underscore the importance of efficiency and productivity in the future development of Irish dairying. However, the terms 'efficient' and 'productive' are laden with many connotations. The following sections will dissect the very specific way in which these terms should be understood throughout the remainder of this thesis.

Positive and normative aspects of efficiency

Economic theory has both 'positive' and 'normative' aspects.[1] The point of departure between the two is in the nature of the questions the researcher asks. The 'positive' approach is concerned with observation and measurement of 'what is', whilst normative economics addresses inquiries of 'what ought to be'. Both aspects are rigourous; they are equally concerned with data and mathematical modelling. Moreover, both sorts of research are valid and necessary. This thesis will attempt to contribute mainly to the positive literature to the extent that it is possible to remain solely in one category or the other.

All manner of economic phenomena have these 'positive' and 'normative' connotations associated with them; matters of productivity and efficiency analysis are certainly not exceptions to this rule. There are at least two ways in which 'normative' aspects of efficiency—in particular—may enter into such a discussion. Firstly, the chosen definition of efficiency will bring with it certain additional normative 'baggage' as will be seen in the next section. In the section which follows on from that it is shown that the choice of mathematical formulae for teasing out measured efficiency from statistical data is not a strictly 'positive' affair either. These two sections give the rationale for the choice of approach used in the remainder of this thesis.

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[1] The term 'positive' here is the result of the literary tradition. It is understood that 'normative' economics is not 'negative', nor that 'positive' economics is in any way 'better', more scientific, or more substantive.

Views of efficiency: Farrell and Leibenstein

Being situated in the area of production economics, this thesis is concerned with productive efficiency. This view of efficiency differs from definitions that enter into the welfare economics literature, e.g. Pareto-efficiency or Kaldor-Hicks efficiency. Yet even within production economics there are competing theories of the firm which imply different views of efficiency.

One can trace the roots of the positive tradition of productivity analysis back at least as far as Debreu (1951) whom contributed by proving the existence of a 'coefficient of resource utilization'. Farrell (1957) applied this result—and also further work by Koopmans and Carter (1952)—to the specific question of measuring productive efficiency. For Farrell, the discipline had failed to construct any satisfactory measure of efficiency '...partly due to a pure neglect of the theoretical side of the problem.' Despite this criticism, Farrell's primary focus was on quantifying efficiency; he was far less concerned with describing an explanatory process for the emergence of inefficiency as a phenomenon.

By contrast, Leibenstein (1975; 1978) provides a description of the means by which a firm may become inefficient. Leibenstein's X-efficiency provides a framework for understanding departures from optimal behaviour. These explanations mainly hinge on the idea of misaligned incentives, e.g. principal-agent problems. However, such theories find a natural home in the description of large organisations, with many layers of management between the owner of the firm and its day-to-day operation. This would not describe the typical situation on a dairy farm in Ireland, nor indeed, in most of Europe where the family farm model is dominant.

Later chapters of this thesis attempt to statistically tie certain variables of interest with efficiency effects, but these need not have a basis in the psychology or strategic motivation of the participants in the production process. Instead, they are viewed as features of the process itself. Therefore, this work follows the Debreu-Farrell tradition, rather than that of Leibenstein.

Econometric and deterministic approaches

Coelli et al. (2005) categorise the research techniques associated with modern productivity analysis under three broad headings; these are the index number approach, Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA). Both DEA and index numbers are non-parametric approaches to efficiency measurement, whilst SFA is a parametric—or sometimes a semi-parametric—econometric approach.

Of these three methods, index numbers are primarily used for sectoral or national measures of Total Factor Productivity (TFP). In index number approach, sector-level aggregate time series are used to construct a TFP index through the application of various formulae. However, such a measure was constructed in Chapter 4 using parameters from an econometric SFA model to allow a decomposition of TFP. Farm level measures of efficiency were of interest in Chapter 6, as were the factors which influenced them. Both DEA and SFA techniques are more suited to this level of analysis. Index numbers were used as input prices in the estimation of a cost frontiers estimated in Chapter 6, but these were directly available from Eurostat; they required no special calculation on the part of the author.

DEA and SFA both attempt to measure firm level efficiency by constructing efficiency frontiers against which individual data points are compared. Where they differ is the method by which these frontiers are constructed.

DEA is deterministic in nature, i.e. it has no random component, so it requires less in the way of statistical assumptions to calculate its measure of efficiency. It is an exercise in mathematical programming; it is not an econometric technique, although it uses real data in the construction of a frontier. This fact brings with it two drawbacks. Firstly, the statistical properties of the generated efficiency measure are unknown. Historically, DEA estimates had no standard errors attached to them at all, although this has changed in some of the latest models. Secondly, this approach does not account for statistical noise; hence, the entire distance to the frontier is attributed to inefficiency.

On the other hand, SFA does explicitly account for statistical noise. The cost of this advantage is the requirement of the specification of a functional form for the frontier, and an assumption as to the shape of the probability distribution associated with the inefficiency term. These are two strong assumptions. The first can be made somewhat less consequential by the specification of a so-called ‘flexible functional form’, but there is no theory to guide the practitioner with regard to the correct choice of efficiency distribution.[2]

Stochastic frontier models were estimated for both TE and CE despite the strong assumptions required. In the context of agricultural production, where elements as

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[2] This is no panacea. Second order flexible functional forms make no guarantee of conformity with regularity conditions. It will be possible to impose these conditions on certain forms, but the act of doing this may in fact destroy the function’s flexibility (Sauer 2006, p.1065). Until there is a definitive result from the theoretical literature on this point, the choice of functional form—which implies a trade-off between specification error and fidelity to the axioms underpinning microeconomic theory—remains an idiosyncratic one.

capricious as the weather can drastically affect efficiency measures, and possibly also the magnitude of effects of the drivers of efficiency, it was deemed that the explicit allowance for random movements of the frontier was worth the strong methodological assumptions necessary to achieve the analysis. The reader should note Farrell's prescient warning regarding an "engineer's approach" to comparing firms and industries to each other.

> "Although there are many possibilities, two at once suggest themselves—a theoretical function specified by engineers and an empirical function based on the best results observed in practice. The former would be a very natural concept to choose—after all, should not a postulated standard of the perfect efficiency represent the best that there is theoretically attainable? Certainly it is the concept used by engineers themselves when they discuss the efficiency of a machine or process. However, although it is a reasonable and perhaps the best concept for the efficiency of a single production process, there are considerable objections to its application to anything so complex as a typical manufacturing firm, let alone an industry." (Farrell 1957, p.255)

Of the two approach described in the quote, DEA is closer to an engineers' approach. Farrell could not have foreseen the sophistication of modern DEA, and it must be said that it is not merely a 'theoretical function' but also 'empirical', as it does construct its frontier around real world data points. However, DEA's inability to account for the random nature of production is reminiscent of Farrell's original concerns. It seems a cold comfort to have insulated oneself from specification error and a possibly incorrect distributional assumption if the cost of this protection is either a complete lack of a random term, or else standard errors with no known statistical properties, thus undermining the inferences one would make from such a model.

Selected literature regarding productivity and efficiency

Much effort is now being put into understanding the competitiveness of dairy sectors in the various EU member states in anticipation of the abolition of milk quota. Abdulai and Tietje (2007) used a `true' random effects model to estimate the technical efficiency of individual farms in northern Germany, as well as estimating efficiency with more conventional panel data models. This model will be discussed in Chapter 4, but a brief description of the benefit of this approach is as follows; it allows technical efficiency to be estimated whilst accounting for unobserved farm heterogeneity and without assuming that the technical efficiency of a given farm is fixed over time. Their results supported the notion that inadequately dealing with farm heterogeneity in the data results in technical efficiency estimates which are confounded with the heterogeneity, hence the technical efficiency estimates will be biased downward.

Maietta (2000) opted for a shadow price approach to measuring inefficiency. Maietta decomposed inefficiency into technical and allocative inefficiency, allowing the former to be modelled in a fixed effect term but keeping the allocative inefficiency through input specific parameters that scale market prices. The model was then applied to panel data of dairy farms in Northern Italy, with the resulting estimate of cost excess due to inefficiency at 69 percent. Most of this inefficiency was due to technical inefficiency. Most of the allocative inefficiency was found to be due to under-utilisation of forage crops and of purchased feeds with respect to hired labour.

Looking toward North America, Paul et al. (2004) use both SFA and DEA models to compare the competitiveness of small family farms relative to large industrial farms using a panel of farms in the corn belt of the U.S.A. Competitiveness was measured in terms of scale economies and technical efficiency. Their analysis concludes that small family farms were both scale inefficient and technically inefficient.

Nehring et al. (2009) researched the competitiveness of small farms in the U.S.A. using panel data ranging from 2003 to 2007. They also used a SFA model to compare the performance over time of conventional and pasture technologies which they identified using a binomial logit model. They too found that large conventional farms won out in most economic measures

Gillespie et al. (2009) used a multinomial logit model to compare the profitability of U.S. dairy farms based on production systems in three classes: pasture-based; semi-pasture-based; and conventional. Whilst they found that region, farm size, and demographics affect profitability, they also found that a conventional system was more profitable than a semi-pasture-based system. However, they were unable to find evidence of an effect on profitability with respect to the choice of a pasture-based system as opposed to the other systems.

Hailu et al. (2005) used two non-homothetic translog stochastic meta-frontier cost functions to estimate cost and input demand functions for pooled data from Alberta and Ontario provinces in Canada. The average cost efficiency was approximately 89 per cent, so the authors conclude that the sector has scope to improve. They also examined the relative competitiveness between the two regions, but were unable to draw conclusions regarding this comparison as the data did not provide any statistical evidence of any difference.

Some notable studies from the Southern Hemisphere include two papers by Doucouliagos and Hone (2000) and Conradie et al. (2009). The former used a SFA model to analyse the productivity of the Australian dairy processing sector. They found that a recent trend towards deregulation of the industry there coincides with a slowdown in productivity growth and technical progress. Conradie et al. (2009) used South African agricultural census data from 1952 to 2002 to examine productivity growth, and also to extoll the benefits of disaggregating the data below the national scale to reveal regional trends.

1.4 Contributions of the work

This section describes the anticipated impacts and contributions to the literature which will result from this thesis. The section also enumerates various ways in which the research has already been disseminated before discussing a data contribution to the agricultural research community.

The analysis in Chapter 4 examines trends in an index of TFP which extends to before the implementation of milk quota. Additionally, the index is constructed from a microeconometric model, and this allows a decomposition which can be used to understand which components of TFP registered changes as the policy came into force. This contribution informs the economic literature as it relates to production constraints generally, as well the policy literature concerning milk quota more specifically. It is unique in its ability to construct the index from microdata over such a long time period.

Chapter 5 takes a novel approach to the question of how milk quotas affected the distribution of farm income. The discussion of milk quota's effects usually focuses on sector level results, but even when farm level analyses are undertaken, these centre on average effects and outcomes. The research presented in Chapter 5 is novel in its emphasis on whole distributions farm income, and in its design of a natural experiment to identify a causal effect from quota policy. The results provide some empirical validation of a theoretical result by Guyomard et al. (1996), and they have policy implications in that they suggest the removal of quota disadvantages smaller farmers.

To the best of the author's knowledge, the study of the efficiency effects of grass utilisation presented in Chapter 6 provides the first estimated effect for this particular input. There is already a technical literature concerning this point, but experimental data may lack external validity, hence this work provides support in its use of real-world production data. The direct policy implication is that continued research and extension is warranted in the case of optimising grass utilisation in Ireland, and in regions of the EU which are located in the Atlantic plains zone.

Work from this thesis has been submitted to conferences and presented regularly throughout the duration of this doctoral programme. A list of these activities is given in this section. Work has also been presented several times at internal seminars within the National University of Ireland, Galway (NUIG) and at Teagasc, but these are not listed.

Presentations

Table 1.1 Research outputs-works presented and media

"A comparison of dairy production systems in Ireland and Northern Ireland" presented at Dairy Expansion Seminar Series, Seminar No 1. Horse & Jockey, Thurles., March, 2014.
"Grass utilisation as a driver of efficiency on European dairy farms" presented at Teagasc Annual Walsh Fellowship Seminar. RDS, Dublin., November 2013 (**competition winner**)
"Grass utilisation as a driver of efficiency on European dairy farms" presented at AESI Annual Conference. Teagasc, Ashtown, October, 2013
"A comparison of dairy production systems in Ireland and Northern Ireland" presented at AESI Annual Conference. Teagasc, Ashtown, October, 2013
Gillespie, P. R., Thorne, F. S., Hennessy, T. C., O'Donoghue, C., & Hynes, S. (2014). Grass use and cost efficiency. *TResearch, 9*(1), 9.

Works related to the analyses in Chapter 4 and Chapter 5 were presented to the Agriculture Economics Society of Ireland at Ashtown in late 2013. In November of the same year the presentations on the efficiency effect of grass utilisation won the overall prize for the Teagasc/RDS Walsh Fellowship Seminar. The Teagasc/RDS Walsh Fellowship Seminar received several hundred submissions from Walsh Fellows throughout Teagasc, and these were across all disciplines in the natural and social sciences. This award was the first award given for a presentation by an economist in 18 years, and the first given to a Walsh Fellow associated with the Rural Economy and Development Programme (REDP) within Teagasc. This also resulted in an article in Teagasc's research extension magazine, TResearch.

The presentation at the event at the Horse & Jockey was not as the result of a submission, but an invited presentation which was delivered to Teagasc researchers and industry stakeholders. The presentation received some coverage in the national media.

Full papers

Later stage submissions include papers associated with Chapter 4 and Chapter 6 - both of which were accepted as contributed papers to the general session at the Agricultural Economics Society (to which the AESI is the Irish branch), and an acceptance for a full contributed paper to the International Congress of Agricultural Economists.

Table 1.2 Research outputs-contributed papers

"Milk quota and the development of Irish dairy productivity: a Malmquist index using a stochastic frontier approach" (ID:968) Contributed Paper at the 29th Triennial Conference of the International Conference of Agricultural Economists (ICAE) in Milan, Italy from 9 to 14 August, 2015.
"Grass utilisation as a driver of efficiency on European dairy farms ", contributed paper in the 89th AES Conference, Warwick, UK, 13-15 April 2015
"Milk quota and the development of Irish dairy productivity: a Malmquist index using a stochastic frontier approach", contributed paper in the 89th AES Conference, Warwick, UK, 13-15 April 2015

Acceptance into the ICAE is particularly difficult. All submitted papers were subjected to double-blind review and subsequent scrutiny by a Track Chair expert in the subject area. Close to 1,100 submissions were made for the limited number of available presentation slots. These successful submissions represent a major affirmation of the quality of the work contained in this thesis, and they will guide forthcoming journal submissions.

Table 1.3 Research outputs- deliverables

"Determining the Sources of Efficiency on Livestock Farms". Project deliverable for MultiSward: Multi-species swards and multi-scale strategies for multifunctional grassland-base ruminant production systems. FP7-244983.

Some of the work was part of an EU framework project. As such, this work is already informing policy makers. Articles based on the work contained in this thesis will be submitted to journals over coming weeks.

Data contribution

The National Farm Survey provides an unparalleled view into the decision processes of Irish farmers through its wealth of variables. The data provides socio-demographic data alongside farm accounts and some of the most detailed agricultural production information one is likely to find. Another output from this thesis gives the NFS data the capability to observe farm level reactions to external stimuli—such as policy changes or macroeconomic developments—from as long ago as the start of the 1980's.

The author's part in this project involved two major tasks; code had to be adapted to calculate the derived NFS for the years 1979-1983, and the system of weights which makes the sample representative had to be recovered. The author was able to accomplish these tasks for the subset of Specialist Dairy farms in the course of this doctorate programme. Hence extended data for Specialist Dairy farms are now available to those whom have a need for it.

1.5 The structure of this thesis

This section gives the overarching structure of the thesis. The thesis' overall objectives can be summarised as follows:

1. to establish long term productivity trends using farm-level data (Ch. 2,3, and 4),

2. to quantify and decompose TFP for Irish dairy farms (Ch. 4),

3. to examine the distributional effects of milk quota policy (Ch. 5), and

4. to assess the effect of grass utilisation on dairy efficiency (Ch. 6).

Chapter 2 will examine the recent history and the current state of the dairy sector in Ireland in order to provide policy and structural context. The reader is introduced to key trends and indicators of structural change to support the modelling exercises carried out later. The policy context in which the sector has developed since the 1970's is presented before the chapter reviews the structure of the sector, and lastly it examines the sector's economic performance as far back as 1995.

Chapter 3 describes the extension of the National Farm Survey to historical periods for which the original data has only recently been digitised. Descriptions of the two datasets which best fit the thesis' data requirements are given, and justifications for the choice of data for each chapter are also provided. This leads to a discussion of the practical need to extend the NFS data, the method by which this is accomplished, as well as some methodological issues which are important.

Chapter 4 utilises a long panel of specialist dairy farms recently made available from the NFS. The long time-horizon of the newly-extended data allows for an expansion of previous studies of TFP, whereby trends in the index are now observable from before the implementation of milk quota.

Chapter 5 compares the specialist dairy sectors of Ireland and Northern Ireland. The salient feature of this comparison is that milk quota has been non-binding in Northern Ireland since the quota reforms of the mid-1990s, whereas quota has been a binding constraint in Ireland throughout this period. Therefore, the comparison is cast as a 'natural experiment' in milk quota policy. The experimental design is used as a vehicle for an analysis of the distributional effects of milk quota on farm income.

Chapter 6 explores the interaction of grass utilisation and the region in which a farm is located as it pertains to its technical and cost efficiencies. The reader is exposed to the existing literature on the determinants of technical efficiency before the chapter reviews the relevant economic and methodological theory. Results are generated for several different groupings of farm, i.e. frontiers are estimated relative to each MS first and then by bio-economic zones.

Chapter 7 draws conclusions from—and connections between—previous chapters, as well as suggesting areas for future research. Summaries of the main findings of each of the empirical chapters are provided. The chapter then discusses some of the more applied literature which has not been directly addressed by the methodology employed herein, yet which may qualify the research findings to some degree. The thesis' final section concludes with suggestions for future research.

Chapter 2 Trends and developments in the dairy sector

2.1 Introduction

Analyses of milk quota's effects must be placed into proper context both in terms of the wider policy environment, and in terms of the structural development of the sector. Agricultural policy originates at several levels of government and is multi-faceted, so an understanding of the history of relevant policies which are not directly related to quota is important. Furthermore, markets, production environments, and cultural norms all impose structures on the dairy sector. These structures have an effect on the development of output, productivity, and efficiency. Therefore, it is critically important to be cognisant of this background in order to gain any insight from subsequent analyses. To this end, this chapter presents the requisite trends and developments within the Irish dairy sector.

Irish dairying shares the competitive advantage of a grass-based production system which is common to all Irish livestock production, but it also possesses some unique strengths. As compared to the other livestock enterprises the level of dependency on direct payments is far lower in dairying. Furthermore, changes in policy as well as the current levels of structural indicators favour an expansion of Irish dairy production over the next several years. Indeed, even as the entire agricultural sector has been cast as an engine of an export-led recovery from the global financial crisis of 2008, it is the dairy sector that has the most ambitious growth targets.

Although historically the beef sector was by some way the larger of the two sectors in Ireland, the dairy sector's share of output value has increased quicker since Ireland's accession to the European Union EU. Whilst both sectors continue to account for a substantial share of agricultural output, developments in policy as well as changing consumer preferences in global export markets have resulted in milk production becoming the largest contributor to the overall value of Irish agricultural output. As of 2011, milk production accounted for 28 percent of all agricultural output at basic prices.

This plurality contribution to output is one measure of the sector's importance, but so too are its linkages with other sectors, and this is particularly visible in the case of the beef and crops farming. The supply of calves to the beef sector that results from increased dairy production is quite substantial; only about a fifth of dairy calves are normally required for replacement of the national herd, so the residual 80 percent is sold off into beef. In a similar manner, the dairy herd's consumption of feedstuffs has important ramifications for crop production.

The structure of the chapter is as follows. Section 2.2 presents the broader policy context in which the dairy sector operates. Section 2.3 relays the relevant historical trends and structural developments. Section 2.4 reviews the dairy sector’s recent economic performance, and section 2.5 concludes.

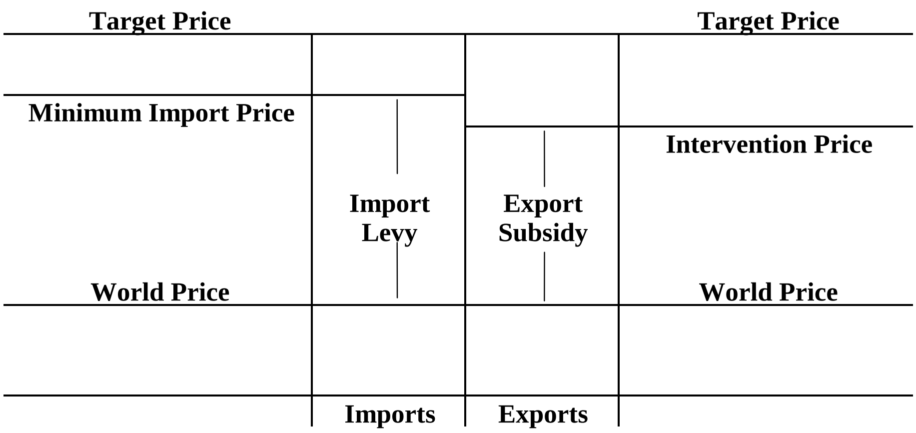
2.2 Policy Context

In this section the support system operated by the EU is detailed. An understanding of the various components of this support system is a necessity, and one needs to pay particular attention to the evolution of these support structures as various rounds of World Trade Organization (WTO) negotiations have led to significant changes in the CAP.

The Common Agricultural Policy

As with all of European agriculture, EU policy is of critical importance to the Irish dairy sector. In the period prior to entry to the then European Economic Community (EEC), the only market to which Irish dairy produce had access on any meaningful scale was the United Kingdom (UK). The access to continental European markets which EEC accession provided allowed Ireland a greater diversity of export opportunities, and also placed the Irish dairy sector under the considerable influence of the Common Market Organization (CMO).

Figure 2.1 Historical CAP pricing system for the dairy sector



Source: Buckwell et al. *(1997)*

Figure 2.1 gives the price support system as it has historically operated in the dairy sector. On the import side, a minimum import price was established relative to a notional target price. The difference between the world price, and this minimum was closed by an import levy. On the export side, the difference between the intervention price (minimum export price) and the world price was covered by an export refund, i.e. subsidy.

Both negotiations with the WTO and budgetary pressures have provided an impetus for changes to the organisation of the CAP. The previous experience of so called ‘butter mountains’ led the European Council to introduce an intervention limit of 180,000 tonnes for butter from 1987. It was decided that agencies would buy in butter beyond this amount only on a tender basis, and even then certain restrictions would apply. A payment delay was also introduced.

Buying in of SMP was able to be suspended at a level of 109,000 tonnes, and even below the limit intervention operated only though the peak production months. Quality criteria were introduced, as were payment delays.

As well as being a severe burden on the CAP budget, intervention has been politically unpopular with the general public. In response, the EU shifted its focus away from intervention and towards subsidised consumption/disposal as a means of handling excess dairy commodity supplies.

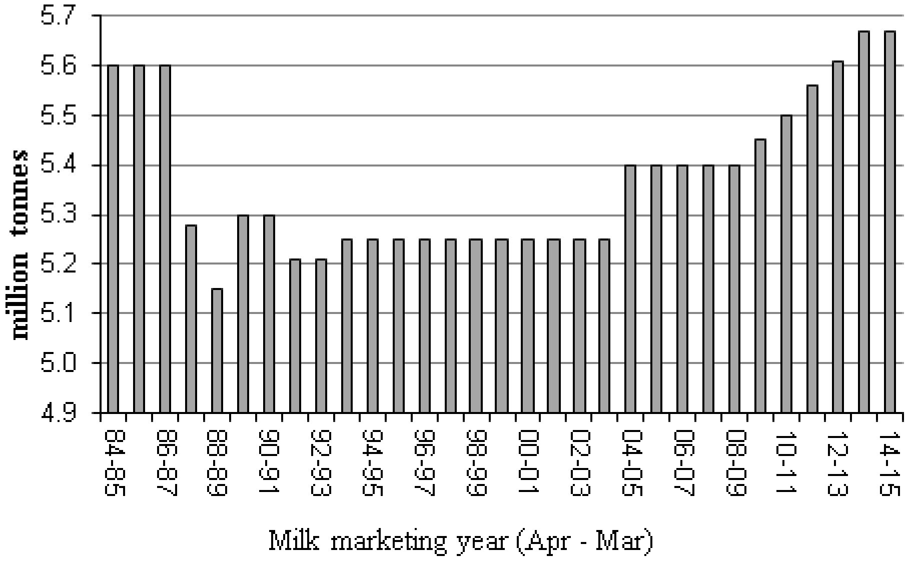
The super levy or milk quota system was introduced in 1984. Its purpose was to contain the growth in milk production so that the EU’s agriculture budget can manage the cost of the price support framework. Under the quota arrangement, each member state has a reference quantity, with each producer in turn having an individual reference quantity. Milk delivered is tested against a reference milk fat level. If the milk delivered exceeds the reference milk fat level then an adjusted milk volume is calculated for quota purposes. If the adjusted milk volume exceeds the reference volume then this will trigger a super levy payment on the excess. Historically, this fine was set at 115 percent of the target price for milk, but with Reg (EC) 1788/2003 super levy payments were set on a fixed schedule until quota abolition.

Quotas were initially attached to land and could not be freely traded, but since 1992 greater flexibility has been introduced to the quota regime, culminating with a market mechanism for quota being introduced in 2007.

From an economic perspective quotas, it could be argued, have been the cause of some stagnation in the sector since they protect less efficient producers by acting as an entry barrier against new producers and hinder the expansion of output by the most efficient of existing producers. However, structural change at farm level has been helped by the creation of national reserves for the allocation of quota to special cases and also by the adoption of national and EU schemes to buy up quota from producers who wish to leave milk production, e.g. the Milk Outgoers Scheme. Indeed, in the case of Ireland, it must be questioned whether quotas have brought about stagnation given that the number of milk producers has fallen by half since the quota system was introduced (Fingleton, 1998).

Figure 2.2 shows quota volumes allocated to Ireland since the introduction of the quota system. The first three years of the policy see a level of 5.6 million tonnes of milk equivalent before that figure drops swiftly to 5.15 million tonnes in the 1988-1989 milk marketing year. The reference level varies in the early 90s, but the MacSharry reforms usher in a stabilised quantity at the 1993-1994 level through the 2003-2004 milk marketing year. After the 2003 mid-term review of the CAP the reference level immediately jumps to 5.4 million tonnes, which is followed by annual increases starting in 2009-2010 and continuing until the final two years of the policy. The initial reference quantity is not seen again until it is slightly surpassed in 2012-2013, i.e. 28 years after the policy was first implemented.

Figure 2.2 Milk quota national reference levels



Source: Compiled from Donnellan (2000) and, Reg. (EC) 1788/2003 Annex I

The quota system helps to maintain dairying in less competitive areas. For those farmers already in operation at the time of the introduction of the quota system it gave them, free of charge, a license to produce milk which they would eventually be able to sell or lease.

The CAP reform of 2003 set the date for the abolition of milk quotas at 2015, with incremental increases in the years running up to this date. This development presents an opportunity for countries that—like Ireland—are more than self-sufficient in milk production, as it will mean increased access to export markets.

Environmental Policy

Many of the policy mechanisms in the CAP attempt to strike a balance between supporting vulnerable rural communities on the one hand, and liberalising international trade along the lines of WTO agreements on the other. However, more emphasis is progressively being given to managing the interactions between agricultural activities and the environments in which they occur. The two major areas of policy pertain to climate change and the protection of water sources.

The need for specific climate policies stems in part from the signing of the Kyoto Protocol in 1997. Most developed countries were obliged to reduce their Greenhouse Gas (GHG) emissions below the 1990 level to comply with the Protocol, but Ireland received a concession that allowed an increase in its GHG emissions by a further 13 percent above this level by the first commitment period.

In addition, the MS of the EU have also pledged themselves to more ambitious reduction targets under the EU 20-20-20 agreement. This agreement obligates Ireland to reduce national GHG emissions by 20 per cent relative to its 2005 level by the year 2020. This equates to a reduction in GHG emissions of 13,819.68 t CO2 equivalents.

The agricultural sector's contribution to the national emissions total stands at 29 percent in CO2 equivalent terms (EPA, 2012, Table 2.1(b), pg. 37), and this is an unusually high proportion for industrialised nations. Therefore, reducing agricultural emissions will be an important element of any strategy to meet Ireland's obligations under the EU 20-20-20 agreement. However, there were no binding targets for the agricultural sector as of yet, and the expansion targets set out below seem in direct opposition to an overall reduction in GHG emissions. Dairy cows have the highest emissions factor of all livestock in Ireland (EPA, 2012), so any expansion of the dairy herd will increase agricultural GHG emissions by the IPCC accounting system unless it is met with a more than proportional decrease in non-dairy livestock.

The main policy framework for the protection of EU water sources is the EU Water Framework Directive (WFD) (Reg. 2000/60/EC). The EU Nitrates Directive (ND) (Reg. 91/676/EEC) predates the WFD, but it remains the main policy framework through which the agricultural sector aims to achieve broader WFD objectives. The ND mandates MS to control nitrogen and phosphorus pollution through the introduction of a suite of measures under a National Action Programme (NAP). In Ireland, the most recent NAP is called Statutory Instrument No. 610 of 2010, Good Agricultural Practice for Protection of Waters (GAP).

Unlike climate policy, the GAP is a set of binding regulations. Hennessy et al. (2005) assessed the implications for farm profitability of complying with the limits to nitrogen (N) implied by the GAP regulations. Their analysis estimated that 30 per cent of specialist dairy farms and 21 per cent of mixed dairy farms were affected by the organic N limit. Importantly, they found that the impact of the organic N limit on farm profit depended on the farm's stage of development; expanding farms experienced greater losses. They also found that applying the limit on a field-by-field basis reduced farm profit by a much larger amount than if the same limit were applied on a whole-farm basis.

There are a few reliefs from the regulatory burden that the ND regulations impose on the dairy sector. The EU Commission approved derogation for Ireland which allows individual farms to operate at a higher N limit. An additional relief took the form of the Farm Waste Management Scheme (FWMS). The scheme was introduced alongside the new regulations in order to reduce the burden of compliance with the GAP regulations. Applications for the scheme were accepted until December of 2006, and approval meant grant-aid for facilities and for new equipment related to the storage and application of animal manures.

Government and industrial targets: Harvest 2020

In the wake of the global recession of 2008 the Irish government consulted with agricultural and food sector stakeholders to craft a strategy for an export-led recovery for the Irish economy. The result of this consultation was a set of ambitious targets and supporting actions to be carried out by government agencies which were collectively named the ‘Food Harvest 2020’ targets (so named because of the report in which they were introduced). Food Harvest 2020 is not official government policy per se, but it is a collective strategy to which the government has committed itself. The targets are ambitious; the dairy sector's goal is a 50 percent increase in milk production relative to the average production from 2007 to 2009, which amounts to a 2.75 billion litre increase by 2020 according to the (DAFM, 2010, p. 41).

The significance of EU policy in driving the sector's development will diminish as dairying becomes increasingly market-orientated. Both the history of the CAP's evolution over previous decades, and the continued global influence of the WTO suggest at once that policies affecting the dairy sector will proceed to increase exposure to the world market rather than shelter Irish dairy producers in any new way.

However, regulations pertaining to the protection of the environment and animal welfare will persist, thus imposing certain costs that are not faced by international competitors as of yet. Harvest 2020 and ongoing CAP reforms will likely shape the next 10 years of development in the dairy sector. Therefore, policy remains an important factor in the development of the sector in the short to medium-term.

2.3 Structure of the Dairy Sector

This section discusses the development of farm structures in the dairy sector. The structure of the dairy sector can be conceptualised in terms of both physical aspects of the farm and by traits inherent in the farmer. Descriptors such as farmer age and farm size are both appropriately deemed to be structural elements. It is this underlying structure that defines the economic potential of Irish dairying as a whole, and so an understanding of these elements is necessary for constructing a picture of the sector's development over time. It is only then that one clearly understands broad themes such as the intensification and concentration of production in dairying, as well as the importance of increasing yields.

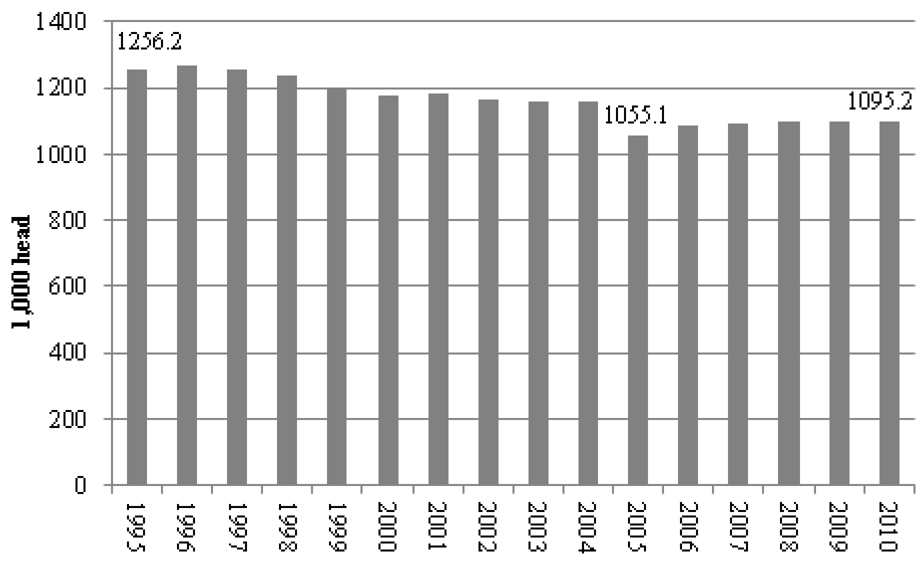
The discussion of farm structures proceeds as follows; first the size of the dairy herd is examined, as this is a fundamental measure of capital structure in the context of a dairy farm. Further physical structures are organised by the forces they best typify, i.e. intensification, concentration, and seasonality. For example stocking rate and milk yield are good indicators of production intensity, so they are presented in that subsection. The final two subsections discuss two measures of human capital—age and education—which are integral parts of the structure of the sector in that they speak directly to managerial capacity.

The Dairy Herd

The size of the Irish dairy herd decreased relatively steadily between 1995 and 2005. The CSO reports that the total number of dairy cows in the national herd stood at 1.26 million head in 1995. Between 1995 and 2005 the herd shrank to 1.06 million head which equates to a 15.9 percent decrease, or an average yearly decrease of 1.4 percent.

The negative trend goes back still further to the introduction of milk quotas; the number of dairy cows was at 1.6 million head in 1984 which corresponds to an annual rate of contraction of approximately 1.5 percent. However, even after decades of gradual contraction there is still approximately 1 dairy cow for every fourth person in the State, and more recent years have seen herd size stabilising.

Figure 2.3 Number of dairy cows (June enumeration)



Source: Central Statistics Office

The dairy herd also consists of other categories of dairy cattle, e.g. bulls, heifers, and calves. These stock categories will also generate both costs and revenue. However, the size of these stocks will be a function of the targeted size of dairy cow inventories, and so Figure 2.3 is indicative of those stock movements as well. Furthermore, in most years output categories such as calf sales will tend to offset costs associated with those calves, so they are seen as being profit neutral. Consequently, they are not considered to be drivers of either productivity or profitability in the sector.

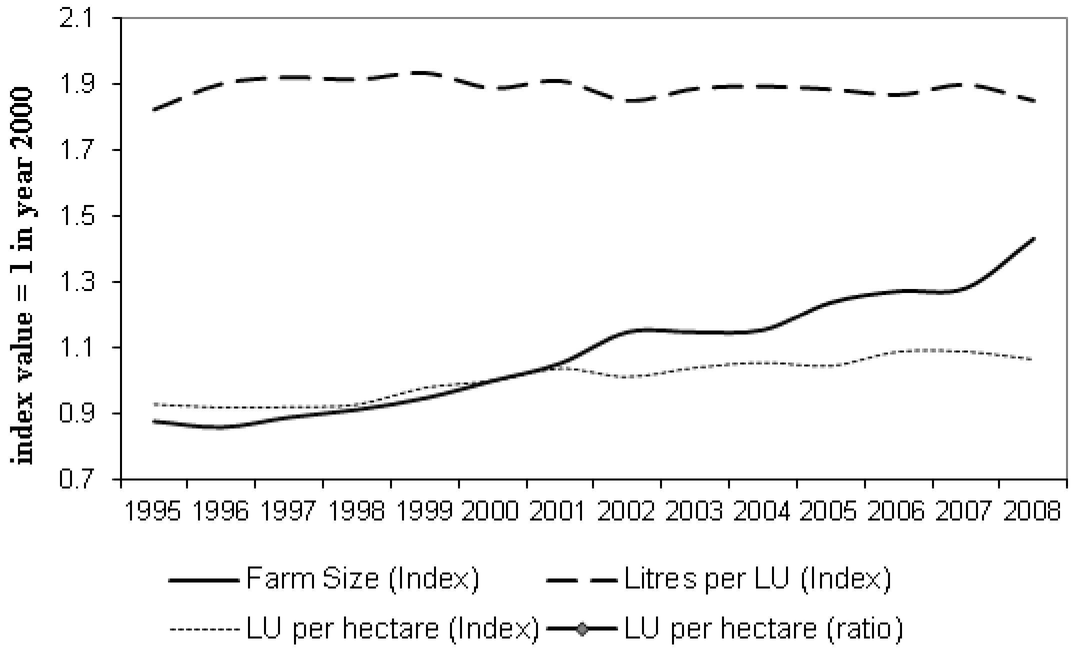
Intensification of Production

When measuring farming intensity by stocking density one finds that the Irish dairy sector hasn't intensified at all in the recent past. The average number of livestock units (LU) per hectare has held steady at approximately 1.8 since 1995. However, stocking densities partly determine eligibility for agri-environmental schemes in the EU, and the WFD prescribes implied limits to stocking rates as well, so a natural ceiling to this figure might be expected. Moreover, stocking densities are not the only available measure of intensity, and at least one other measure leads to a different conclusion. That measure is the intensity of yield per cow.

Figure 2.4 plots yield, stocking density, dairy forage area, and average farm size on the same axes. All were expressed as simple indices, i.e. the value in a given year as a proportion of the corresponding value in the base year.

Unlike the stocking density, the yield has exhibited a gradual positive trend since 1995. In the context of a production ceiling and constraints on stocking density this could be an expression of technical change in the sector (a cost minimisation strategy). Concentration drives the change in the average farm size.

Figure 2.4 Farm size, stocking density, and yield indices



Source: National Farm Survey

Concentration and the structure of milk quota ownership

The Department of Agriculture, Food and the Marine (DAFM) keep records of milk quota ownership over time. These data provide a useful measure of farm numbers. Figure 2.5 displays farms grouped by quantities of milk quota held and expressed as shares of the total number of creamery milk producers. The groups were defined such that they would represent roughly equal shares in 2005, but by 2011 half of all dairy producers control 250,000 litres of quota or more. The share of producers that held 150,000 litres of quota or less declined by a third from just over 30 percent to just over 20 percent. The share of producers that held between 150,000 and 250,000 litres of quota also declined, albeit not as drastically.

Table 2.1 displays the underlying data for this graphic in more detail. The table gives the actual number of producers alongside the percentage shares of the total number of producers, and it does this for more narrowly defined categories. The final row also shows the overall decline in the total number of creamery milk producers as the number of farms exiting exceeds farm entrants over the time period.

These facts affect the interpretation of the strongest trend visible in Figure 2.4—the average—i.e. the average farm size. Farm size is expressed here as a proportion of the farm size in the base year. The trend appears in the late 1990's and persists throughout the rest of the time period; it is apparent that the average farm size is growing. When Figure 2.4, Figure 2.5, and Table 2.1 are taken in conjunction they paint a picture of a dairy sector which has concentrated production more so than it has intensified production. It is this concentration that drives the change in the average farm size.

Figure 2.5 Percentage of milk producers by milk quota held

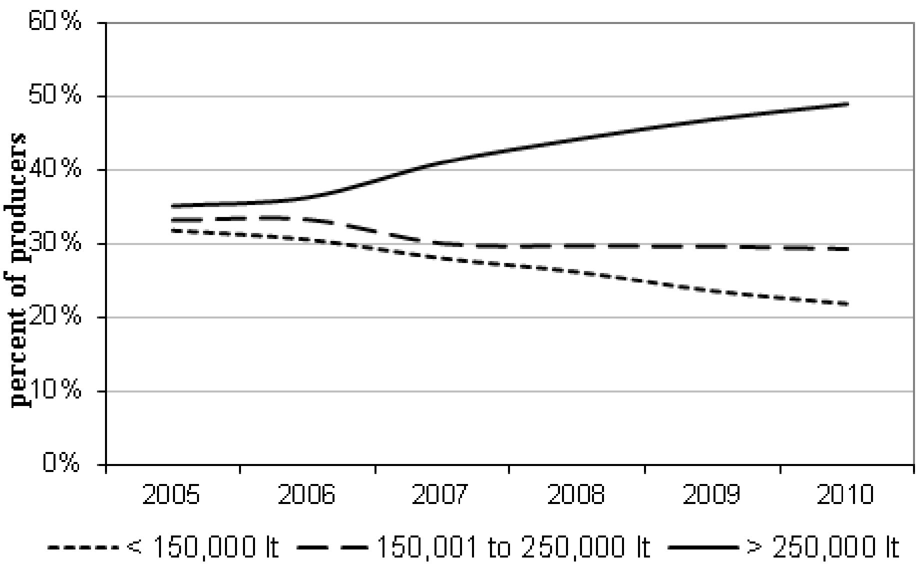


Table 2.1Number and percentage of milk producers by milk quota held

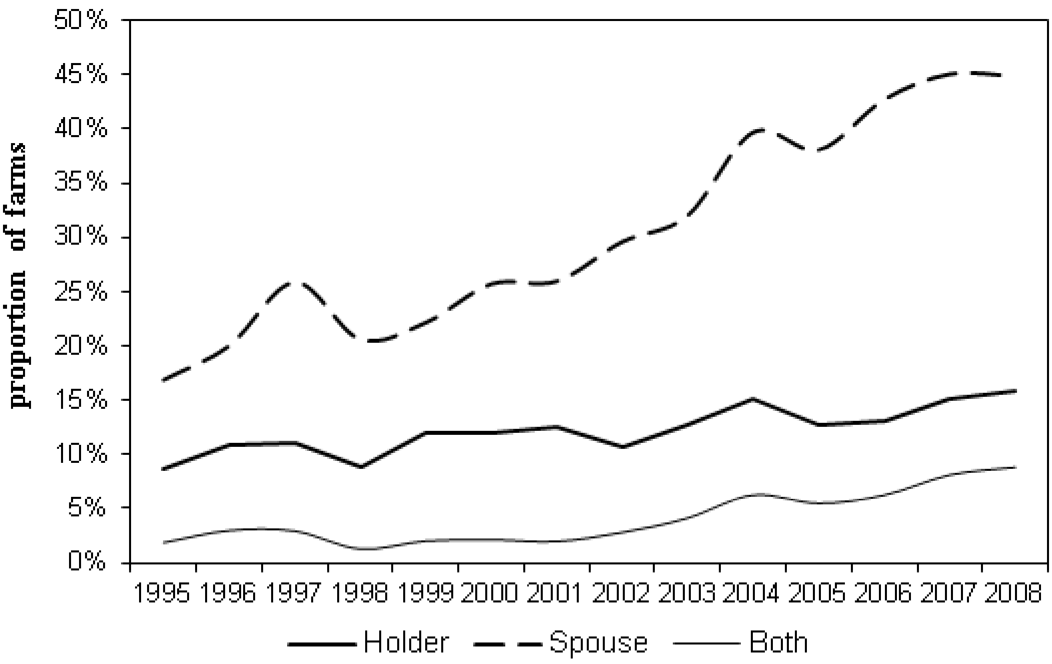
Size Category (litres)	Total Number of Producers currently in Milk Production						
	2005	2006	2007	2008	2009	2010	2011
Less than 50,000	1,179	1,091	911	813	588	446	446
% of Total	5%	5%	5%	4%	3%	2%	2%
50,001 to 100,000	2,672	2,529	2,022	1,831	1,617	1,438	1,359
% of Total	12%	11%	10%	9%	9%	8%	7%
100,001 to 150,000	3,260	3,111	2,635	2,503	2,248	2,103	2,003
% of Total	15%	14%	13%	13%	12%	11%	11%
150,001 to 200,000	3,674	3,601	3,063	2,882	2,737	2,554	2,463
% of Total	16%	16%	15%	15%	14%	14%	13%
200,001 to 250,000	3,751	3,727	3,119	2,960	2,869	2,801	2,760
% of Total	17%	17%	15%	15%	15%	15%	15%
250,001 to 300,000	2,771	2,815	2,306	2,487	2,434	2,402	2,411
% of Total	12%	13%	11%	13%	13%	13%	13%
300,001 to 350,000	1,779	1,762	2,113	1,784	1,842	1,799	1,838
% of Total	8%	8%	10%	9%	10%	10%	10%
350,001 to 400,000	1,206	1,241	1,391	1,448	1,421	1,415	1,436
% of Total	5%	6%	7%	7%	8%	8%	8%
400,001 to 450,000	645	657	798	876	852	889	937
% of Total	3%	3%	4%	4%	5%	5%	5%
Over 450,000	1,449	1,508	1,839	2,102	2,322	2,447	2,610
% of Total	6%	7%	9%	11%	12%	13%	14%
Totals	22,386	22,042	20,197	19,686	18,930	18,294	18,263

Source: Author's calculations based on unpublished data from the Department of Agricultural, Food, and the Marine (DAFM)

Farms that have succeeded in securing more quota and the land to support expansion will have prospered on average, but pressure on family farm incomes for the remainder of dairy farms has resulted in increases in off-farm employment to further support the farm household. The incidence of off-farm employment has been an important shift in Irish dairying. Figure 2.6 shows the evolution of off-farm employment amongst dairy farmers over time.

Whilst the proportion of farms where the farmer held an off-farm jobs has remained at a more or less constant level, the proportion of farms where the holder's spouse was employed off of the farm has shown a strong positive trend since 1995. A related and more recent trend starts from 2001 where the proportion of farms for which both the holder and the spouse are in off-farm employment has also increased.

Figure 2.6 Off-farm employment amongst dairy farmers



Source: National Farm Survey

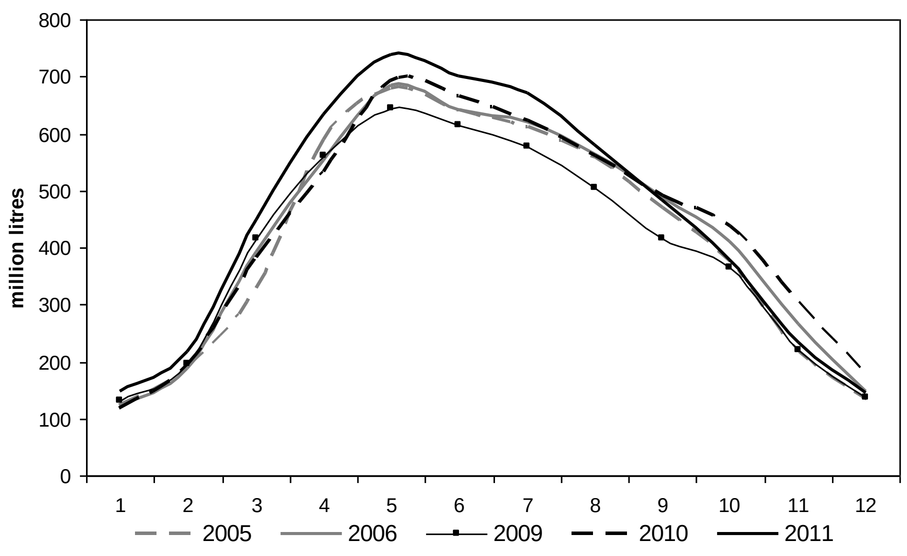
Seasonality of Production

A key difference between agricultural production and production in other industries is the extent of seasonality. Irish dairying displays a production profile across the months of any given year which largely reflects the pattern of grass growth in that year. Figure 2.6 illustrates the cycle; production is at a low in the winter months when grass growth is slow or halted, and it peaks in the late spring and early summer when pastures are developing at their maximum rate.

The management of quota is also useful in explaining the shape of the profile. The milk year starts on 1 April each year and ends on 31 March of the following year. There are stiff 'super levy' penalties for production in excess of quota held. However, bringing cows into and out of production is not an overnight process, so farmers will wind down production as they approach their quota limit. Farmers will ramp up first quarter production only when the end of the current quota year is sufficiently close at hand, so as to avoid excessive super levy payments.

Figure 2.6 shows a selection of years between 2005 and 2011. The year 2007 (not shown) marks the entry of the sector into a period of increased volatility associated with the reduction of market protections provided by the CAP. Nonetheless, one quickly observes that the production profile does not tend to change very much from year to year. For example, the year 2009 witnessed an historic collapse in milk output prices, and yet the milk profile shows only minor differences from other years.

Figure 2.7 Monthly milk deliveries to creameries (million litres)



Source: Central Statistics Office

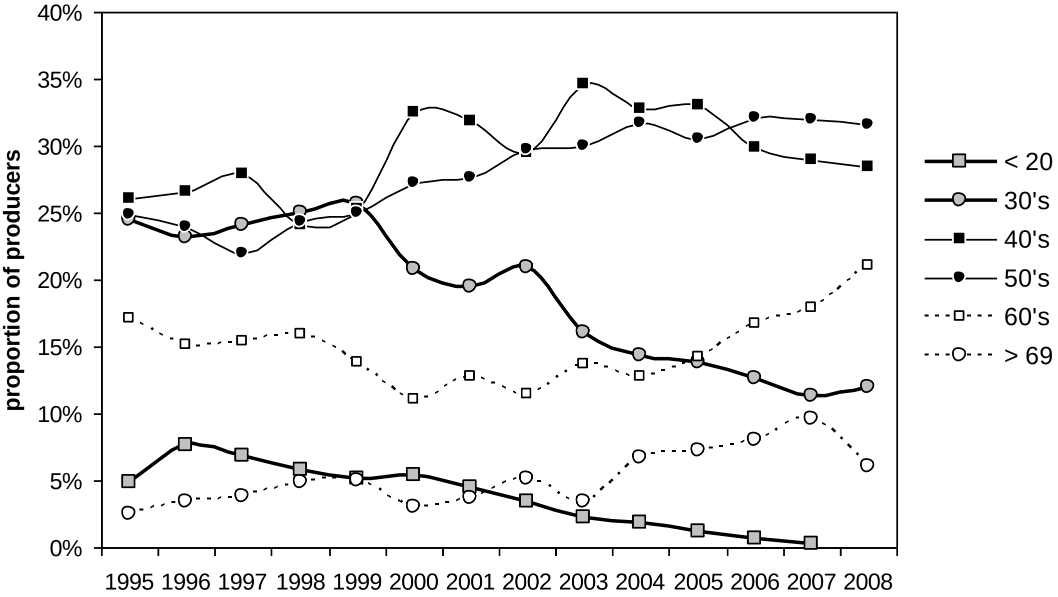
Farmer age

Farmer demographics are an important descriptor of the structure of the dairy sector as they are an indicator of the state of human capital. The age distribution will have implications for technological development and efficiency in the dairy sector.

Graphics such as Figure 2.7 then imply a challenge as the share of older age categories have trended upward for much of the time period between 1995 and 2008. Indeed, the ‘less than 20’ age category drops off the chart completely. This trend is part of the effect of the Celtic Tiger years on agriculture at large, but it does not include the recessionary years since 2008–a time in which anecdotal evidence suggests an increase in the number of younger farmers. However, the overall average age for all producers has moved down slightly in recent years.

The last two years of the graphic do show a decrease in the share of the oldest farmer category. This category is open-ended, so as farmers of a very advanced age exit, their absence results in a disproportionate decrease in the average age of all dairy farmers (the age distribution becomes less skewed). This drop in the average age is observed despite evident increases in the share of farmers in their 60’s. There is also a slight but discernible increase in the share of farmers in their 30’s, which also helps to explain the slight reduction in the average age.

Figure 2.8 Trends in dairy farmer age categories



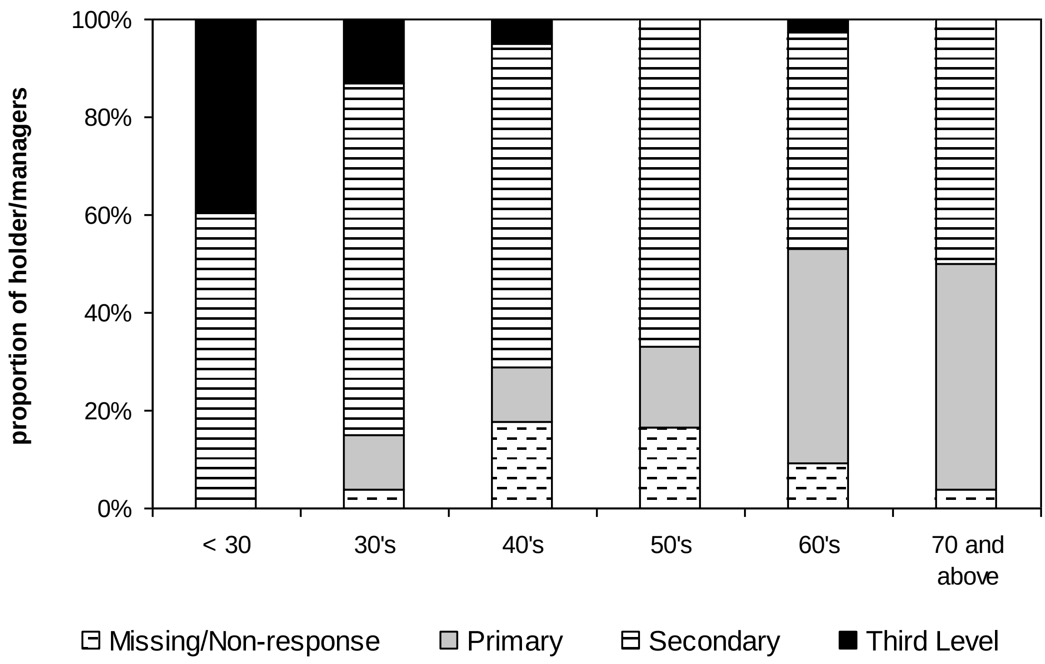
Source: National Farm Survey

Education and extension

Two other important descriptors of the structure of the sector are dairy farmers' levels of education and usage of extension services. Both of these measures are related to the age of the farmer. This fact underscores the importance of age as a structural factor for the sector. Both education and extension services are envisaged as important factors in the adoption of new technologies and management techniques.

The NFS department collected a supplemental survey in 2008. Data was recorded indicating education level and use of extension services by the selected farm households. The portion of the sample corresponding to dairy farmers yields a sample size of 303 farms, and the weighted data represent 18,637 farms nationally. As a once-off survey. The data do not allow inferences regarding trends, but they do provide a relatively recent snapshot of each of these measures of human capital.

Figure 2.9 Education levels by dairy farmer age (2008)

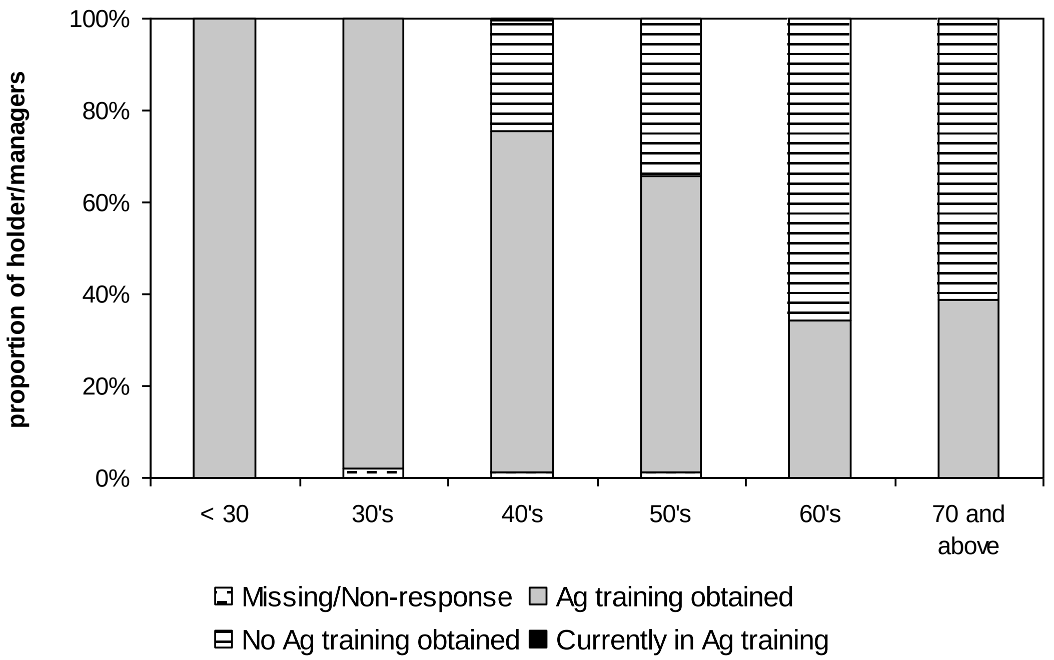


Source: National Farm Survey Supplemental Survey (Holder/Managers only)

Figure 2.8 shows the proportion of several levels of maximum education obtained within age categories of dairy farmers. A clear link between the younger age categories and third level education is evident. Furthermore, a similar link between age and secondary level qualifications exhibits itself; the share of farmers achieving a maximum of secondary level qualifications is roughly constant until reaching the categories of farmers in their 60's, at which point maximum education at the primary level and missing data (which may reflect a lack of any formal education in some instances) begins to eat into secondary level's share. Younger dairy farmers are associated with higher levels of formal education.

Figure 2.9 shows the shares of dairy farmers with or without any formal agricultural training for the year 2008. Younger producers are associated with higher incidence of formal agricultural training.

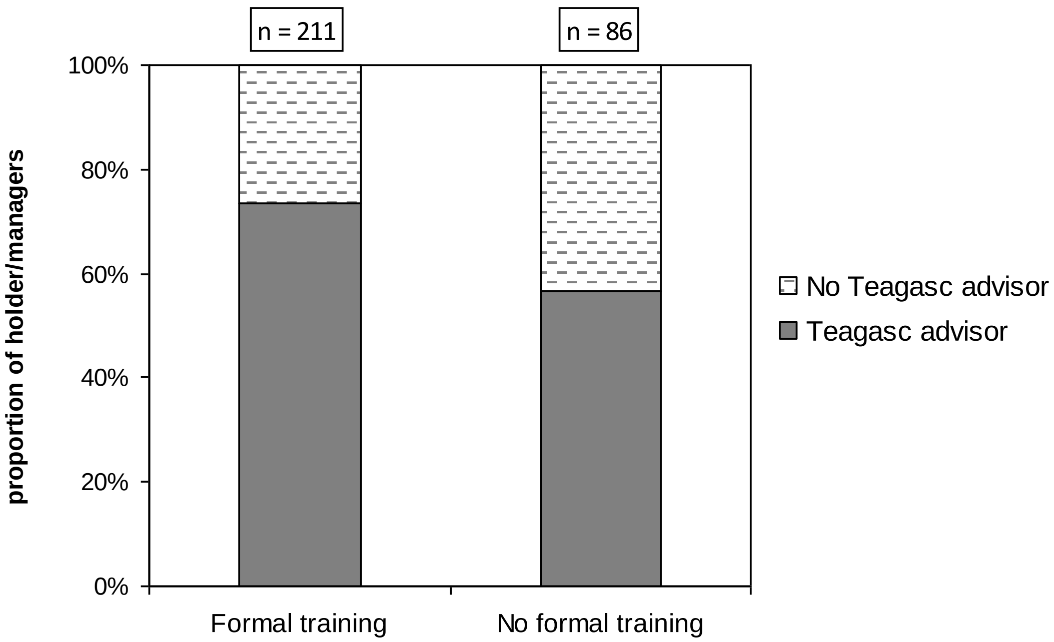
Figure 2.10 Formal agricultural training by dairy farmer age (2008)



Source: National Farm Survey Supplemental Survey (Holder/Managers only)

The relationship between training and the usage of Teagasc advisory services is portrayed in Figure 2.10. Here, the existence of Teagasc advisory fees in the NFS data indicates the use of a Teagasc advisor. The figure shows a clear correlation between utilisation rates and the presence of formal agricultural training amongst dairy farmers. To the extent that Teagasc extension services keep farmers informed of evolving best practices and strategic outlooks, formal agricultural training appears to confer continuing benefits through higher utilisation of these services.

Figure 2.11 Use of Teagasc advisors amongst dairy farmers (2008)



*Weighted samples were 12,460 and 5,978 farms for the series respectively

Source: National Farm Survey Supplemental Survey (Holder/Managers only)

2.4 Economic performance of the Dairy Sector

The previous section presented the structure of the dairy sector, and now the discussion moves to its recent economic performance. The natural place to start is at the whole farm level. Statistics at this level reflect the performance of farms on which most (but not all) of the revenue is generated by the dairy enterprise, and so they are a good indication of the financial situation faced by these farms. However, it is important to note that this is a more expansive definition of the sector, as non-dairy enterprises will also be included in the figures. Furthermore, specialist dairy producers include those with herds of less than 10 cows and also those whom derive over half of their output from liquid milk sales.

Table 2.2 Whole farm financial results on specialist dairy farms

	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Overall Results (€)							
Gross Output	106,773	108,122	128,564	137,717	109,950	131,717	174,071
of which- Land/Quota Let	147	194	112	132	165	95	191
Direct Payments	18,948	18,790	19,543	20,445	21,255	20,751	23,361
- Direct Costs	36,102	39,128	41,555	50,554	48,389	47,600	60,016
= Gross Margin	70,671	68,994	87,009	87,163	61,561	84,117	114,056
- Overhead Costs	30,877	32,773	35,992	41,432	36,974	39,684	45,486
= Family Farm Income	**39,794**	**36,221**	**51,017**	**45,732**	**24,587**	**44,432**	**68,570**
Net Sales & Receipts	104,891	108,104	127,437	135,999	108,251	130,146	172,290
- Current Cash Expenditure	57,296	61,235	66,203	78,848	74,332	76,152	94,932
= Cash Income (approx.)	47,595	46,869	61,234	57,151	33,919	53,994	77,359
- Net New Investment	11,933	11,728	23,534	40,695	850	11,516	17,091
= Cash Flow	35,662	35,141	37,700	16,456	33,069	42,479	60,268
Asset Values (€)							
Machinery	31,538	34,200	38,958	44,835	47,413	46,302	54,636
Livestock: Breeding	53,724	54,951	58,227	62,763	67,025	67,750	81,138
Trading	20,283	19,760	20,423	22,656	20,799	19,686	26,080
Land & Buildings	701,773	945,619	1,023,544	980,118	892,982	826,528	983,441
Gross New Investment (€)	**13,250**	**13,425**	**27,532**	**48,866**	**13,117**	**13,627**	**19,258**
Loans Closing Balance (€)	**38,589**	**35,273**	**40,363**	**62,169**	**64,279**	**61,012**	**63,768**

Source: National Farm Survey

The NFS farm financial results for specialist dairy producers are given in Table 2.2. The table spans the years 2005 to 2011. Although the overall trend in gross output has been generally positive, the later years show considerable volatility. The year 2009 was severe for many farms, and no figure portrays this as starkly as the level of family farm income. At €24,587 per farm it was less than half the value of the best year to that point (in 2007) and 38.3 percent less than the worst performance (in 2005). The sector had largely recovered by 2010, although family farm income remained below the level attained in 2007. This was due to rising costs which overwhelmed gains in gross output in nominal terms, i.e. without adjusting for inflation.

Dairying then experienced a boom year in 2011 which saw average gross output increase in value by more than 30 percent. Costs also increased, but by a smaller proportion, so as a result family farm income increased by 54 percent. This was a €17,553 improvement on the next highest year in the table, and it occurred only two years after incomes in the sector were at their lowest point in recent history.

Costs exhibited an upward trend over time, but the table shows that 2008 and 2011 were both particularly high cost years. In 2008 direct costs (DC) increased by 20 percent, and overhead costs went up by 15 percent relative to the previous year. In 2011 the year-on-year increases relative to 2010 were 26 percent and 15 percent respectively.

Gross new investment started out near to €13,000 in 2005 and 2006, but then it doubled in 2007, and the annual increase was even larger in 2008. At the 2008 level of €48,866 the average gross new investment per farm was 364 per cent larger than the level of investment just two years prior. With the collapse of output prices in 2009 this figure tumbled back down to earth unsurprisingly, but interestingly never crosses the baseline investment level of €13,000. By 2011 investment had already returned to a level above €19,000.

The year 2008 also marked a shift in the average level of debt held by dairy farms as this figure increased by 54 percent from 2007 to 2008. Much of this likely went towards the financing of investment in 2008 as it increased by roughly the same amount. No great changes in the average debt level occurred throughout the rest of the time period, but there was a much tighter credit environment in those years as the crisis in the Irish banking sector took hold (O’Toole, et al. 2014).

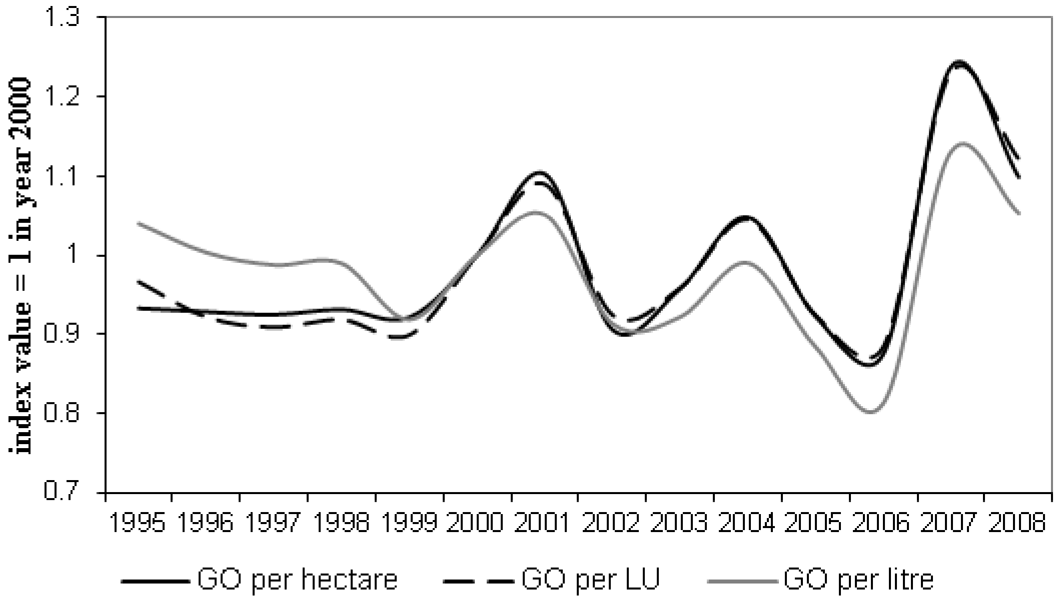
Direct payments to the sector showed a positive trend as they increased by an average annual rate of 3.5 per cent. Many of these payments may have resulted from beef enterprises on dairy farms, although there were still a number of payments which were allocable to dairy enterprises. Despite the increases, the tendency over time was for direct payments to make up a smaller proportion of family farm income on Specialist Dairy farms. However, the year 2009 provides a reminder of just how pivotal this safety net remains. Direct payments constituted all but €3,332 of family farm income in that year.

Output

The value of output is a function of both price and quantity of output. Irish dairy producers operate in a globally competitive market, so they are considered price takers with respect to world market prices. As there is little scope to affect output prices for dairy commodities, any efforts to increase output value necessarily focus on increasing volume. However, all EU dairy farmers operate under a milk quota regime which puts a limit on total production. Recent years have seen incremental increases in milk quota allocations as the regime is phased out and to the extent that output prices have allowed for such additional production the gross output of Irish farms have improved. Output quantities are expected to increase as milk quotas are abolished in 2015.

Figure 2.12 illustrates the development of gross output achieved by dairy farmers using three separate measurement units. Gross output per hectare is a reflection of the available land resource on each dairy farmer's farm, whereas gross output per LU is a measure of yield, and gross output per litre is another expression of the milk price. All have been converted to simple indices (proportions) where the base year is taken as 2000.

Figure 2.12 Gross output indices (Base year = 2000)



Source: National Farm Survey

The figure shows that whilst measures differ somewhat in per hectare and per LU terms in the early period, for most of the last decade the two have been indistinguishable. This is an indication that the gains in output per hectare were a function of price movements and yield improvements, but not changes to stocking density or farm expansion. Measuring on a per hectare basis controls for the farm's size (ruling that out as a driver) and increasing stocking density would appear as a separation between the per LU and per hectare measures. The gross output per litre index and the other two indices have inverted as the downward trend in prices have been partially compensated offset by an upward trend in yields.

Gross output from the dairy enterprise can be decomposed into several parts. Table 2.3 demonstrates that the vast majority of gross output results from sales of creamery milk. This will often be called 'manufacturing milk' and it is the portion of milk that will go on for processing into some intermediate product. By contrast liquid milk (which will also go on to some further processing but is largely a finished product) was actually the smallest contributor to the value of gross output with only 0.1 to 0.2 cent of value being contributed for each litre of output (typically valued above 30 cent per litre). This small cpl figure is not an estimate of the average liquid milk price, but rather it is a reflection of the small size of the liquid milk market relative to that of creamery milk; only about 10 per cent of all milk litres produced in the State are destined for the liquid milk market. Hence, it contributes very little to the average milk price for the sector overall. In actuality liquid milk historically fetched a premium of between three and six cent per litre relative to manufacturing milk, although the two prices have rapidly converged since the announcement of the end of the milk quota policy (O'Ceidigh, 2015).

The net value of calves and cattle was the second largest contributor to gross output, but this revenue source was at its highest in 1995 (near 11 percent of value on a per hectare basis), and this percentage has dropped sharply as the value of creamery milk increased whilst the net value of calves and cattle decreased simultaneously. The value of milk feed has remained steady, but it too was quite small at between 2 and 3 per cent of total output value. The net value of bonuses, penalties, and allowances (policy instruments) was smaller still, and unlike milk feed this category is getting smaller as the CAP undergoes reforms.

Table 2.4(a) gives the price movements of the major inputs expressed as indices where the base year is taken as 2000, whilst Table 2.4(b) reports a variety of output prices experienced by the sector in terms of nominal euro per unit. The table shows that all the major input prices were increasing over time, and the year 2008 was a particularly high cost year. The fact that output prices have not compensated producers for input price movements during this time period is often referred to as 'the price-cost squeeze'. These trends are expected to continue, and they are a major impetus for improving efficiency in the sector.

Table 2.3 Gross output decomposition in euro per hectare (a) and cent per litre (b)**

(a) euro per hectare	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Creamery Milk	2215	2229	2058	2196	2299	2375	2568	2256	2345	2368	2284	2260	2995	2842
Net Value of Calves & Cattle	274	198	184	159	50	99	68	78	82	84	71	68	61	81
Milk Feed	61	74	77	80	70	70	72	76	70	74	72	72	70	75
Net Value of Bonuses, Penalties, and Allowances	18	40	59	64	47	41	52	21	18	23	19	38	30	28
Liquid Milk	0	4	5	7	6	8	13	7	9	12	12	11	10	21
= Gross Output*	**2568**	**2551**	**2387**	**2539**	**2591**	**2715**	**2923**	**2550**	**2650**	**2700**	**2588**	**2580**	**3297**	**3241**

(b) cent per litre**	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Creamery Milk	29.1	28.5	26.0	27.3	26.9	27.7	29.0	27.1	26.8	26.6	26.2	25.1	32.6	32.1
Net Value of Calves & Cattle	3.6	2.5	2.3	2.0	0.6	1.2	0.8	0.9	0.9	0.9	0.8	0.8	0.7	0.9
Milk Feed	0.8	1.0	1.0	1.0	0.8	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.9
Net Value of Bonuses, Penalties, and Allowances	0.2	0.5	0.7	0.8	0.5	0.5	0.6	0.3	0.2	0.3	0.2	0.4	0.3	0.3
Liquid Milk	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
= GrossOutput*	**33.7**	**32.7**	**30.1**	**31.6**	**30.3**	**31.7**	**33.0**	**30.7**	**30.2**	**30.4**	**29.7**	**28.7**	**35.9**	**36.6**

Source: National Farm Survey * Figures may not sum due to rounding error ** gross output contribution / *total* milk litres (creamery milk + liquid milk litres)

Table 2.4 Input indices (a) and output indices (b), base year = 2000

(a) input price indices	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Feed	106	111	104	98	97	100	106	108	108	112	109	111	127	147
Fertiliser	96	101	95	91	93	100	113	111	113	115	124	133	136	221
Other	90	91	93	94	96	100	106	110	114	117	121	124	129	137
Vet Exp.	86	89	92	95	96	100	105	109	115	116	118	122	126	129
Motor Fuel	66	72	74	71	76	100	96	95	99	110	132	144	147	174
Labour	82	85	88	90	93	100	109	115	121	124	136	140	152	157

(b) output prices	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Creamery Milk	100	100	93	97	97	100	103	97	97	97	93	90	117	117
Milk Feed	93	93	100	100	93	100	100	100	93	93	100	100	100	100
Calf transfer (in)	132	111	105	89	87	100	101	107	113	109	105	103	104	105
Calf sale	117	101	80	84	67	100	74	93	106	116	106	97	88	99
Calf transfer (out)	53	66	60	62	88	100	101	87	92	112	112	111	110	99
Cattle purchases	77	64	66	60	74	100	91	101	116	107	107	117	130	128
Cattle transfer (in)	93	84	85	78	98	100	108	111	109	111	112	116	118	123

Source: National Farm Survey

Direct Costs

The cost categories which make up direct costs in a dairy enterprise also exhibit the upward trend which was implied by the increases in input prices from Table 2.4(a). Chief amongst these categories was the cost of concentrate feeds. Concentrates were both the largest cost category in direct costs and the one which has had the largest increase over the past decade. The price of feed in Table 2.4 has increased by 47 percent since 2000, but the total cost of concentrates per hectare from Table 2.6 has increased by 72 percent during the same time period, even as it stayed relatively constant in cent per litre (cpl) terms. This indicates that dairy producers have increased the volume of concentrates fed to the herd on a per hectare basis, but the increase in milk litres has been proportionate to the increased feed expense.

The alternative to feeding concentrates is feeding fodder to the herd. This cost will show up under pasture costs in Table 2.5 and Table 2.6 but the main driver of that cost is the price of fertilisers in Table 2.4(a); Indeed, this price gives an explanation as to why farms would feed more concentrates even as feed prices were increasing; fertiliser prices more than doubled in that time period. Winter forage increased by slightly less, and both show decreasing costs per litre. Given that motor fuels would also be a driver of pasture costs, and that this price also increased by a larger percentage, it appears that any shift towards feeding concentrates over grass was the result of relative movements in the underlying input prices. This being said, Irish dairying remains grass-based.

There were other potential explanations for the differences between percentage changes in input prices and cost categories to which they apply. Firstly, there has been some anecdotal evidence of over-application of fertilisers throughout Irish agriculture, and to the extent that this may also be the case for dairy producers, a reduction in fertiliser application may not necessarily be indicative of a reduction in grass output. Furthermore, as the concentration of farmland in the hands of fewer and specialised producers continues, the reduction of inefficiencies such as the over-application of fertilisers would be expected. Moreover, reductions in fertiliser application would have been effectively mandated by the limits prescribed in the Nitrates Directive.

Veterinary expenses increased significantly over time. These costs were roughly 10 percent of direct costs as well, so disease prevention efforts may well prove to be cost effective.

Of the other direct cost categories, all but two increased over the time period. Miscellaneous direct costs actually decreased by a significant amount. The other cost which did not increase was transport. This cost did end up at exactly the 2000 level by 2008, although there were movements in this cost category in the intervening years

Table 2.5 Direct cost decomposition (euro per hectare)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Concentrates	292	272	221	266	283	276	327	320	314	304	295	362	384	474
Winter Forage	149	156	144	145	156	161	149	169	159	166	177	188	197	222
Pasture	101	105	92	100	110	109	122	121	126	114	126	131	127	154
Vet. And Med.	57	64	62	65	65	76	82	82	88	96	97	99	115	121
Misc. Expenses	109	93	92	95	57	58	48	50	51	55	59	65	73	85
Misc. Direct Costs	81	103	90	96	134	115	118	106	102	98	92	72	73	77
AI and Service Fees	35	36	33	33	32	36	35	34	33	35	34	37	39	43
Casual Labour	8	9	6	11	12	11	9	8	9	10	14	15	17	17
Transport Expense	23	23	20	17	15	13	18	11	14	17	15	15	14	13
= Direct Costs*	**856**	**861**	**759**	**827**	**866**	**855**	**909**	**899**	**897**	**894**	**908**	**984**	**1038**	**1207**

Source: National Farm Survey ** Figures may not sum to Direct Costs exactly due to rounding error*

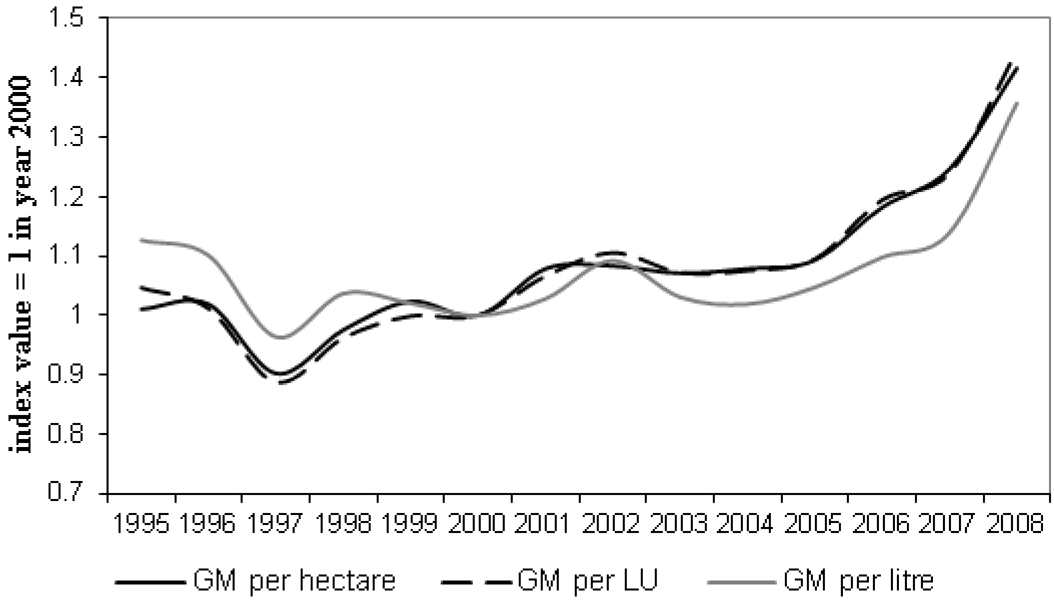
Table 2.6 Direct cost decomposition (cent per litre)

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Concentrates	3.6	3.1	2.7	3.4	3.4	3.2	3.5	3.6	3.3	3.1	3.1	3.6	3.3	3.6
Winter Forage	2.0	2.0	1.9	2.0	2.0	1.9	1.5	1.8	1.6	1.6	1.6	1.6	1.6	1.1
Vet. & Med.	0.9	0.9	0.8	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.1
Pasture	1.4	1.3	1.2	1.4	1.4	1.3	1.2	1.3	1.3	1.1	1.2	1.1	1.0	0.8
Misc. Expenses	1.6	1.3	1.2	1.3	0.7	0.7	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.7
Misc. Direct Costs	1.2	1.4	1.2	1.3	1.6	1.3	1.3	1.2	1.0	0.9	0.9	0.6	0.6	0.6
AI and Service Fees	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.4
Transport Expense	0.5	0.4	0.3	0.3	0.2	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1
Casual Labour	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
= Direct Costs*	**11.2**	**11.0**	**9.6**	**10.3**	**10.1**	**10.0**	**10.3**	**10.8**	**10.2**	**10.1**	**10.4**	**10.9**	**11.3**	**13.6**

Source: National Farm Survey   ** Figures may not sum to Direct Costs exactly due to rounding error*

Gross margin

Figure 2.13 Gross margin (Base year = 2000)



Source: National Farm Survey

At first glance, Figure 2.13 is remarkably similar to Figure 2.12. However, there are some key differences; the years before 2000 appear smoother than in the gross output figure as movements in input prices offset some of those in output prices. However, volatility in the most recent years appears to be more pronounced as changes in costs started to exacerbate output price movements.

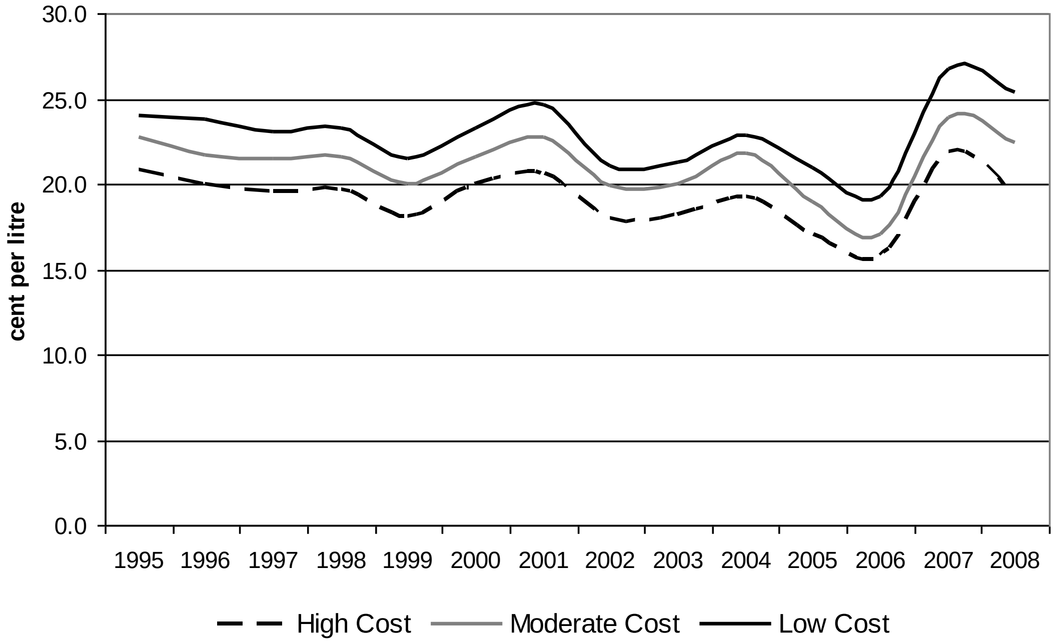
As in the gross output figure, per hectare and per LU measures became indistinguishable by the later years, and the interpretation is the same; yields were driving the sector by this point. Gross margin per hectare and gross margin per LU lines climbed above the per litre series as yield improvements provided some insulation from a negative trend in output prices. One finds that gross margin per hectare—much like gross output per hectare—was driven by output price and yield improvements whilst stocking density was static.

Up to this point the analysis has been concerned with averages for all creamery milk producers, or even broader definitions of the dairy sector, but it is also instructive to distinguish between classes of dairy farmers. These producers were sorted into three cost groupings as defined by average total cost per litre. Each group's average gross margin is plotted in Figure 2.14 and Figure 2.15. The two illustrations differ only in the units of measurement of gross margin they report.

When gross margin is measured on a cpl basis the relative standing between the three cost groups appeared to be static, i.e. the distance between the series was roughly constant. Careful inspection shows some slight separation in the post-2003 period, but no clear evidence of broad structural change was presented in the figure.

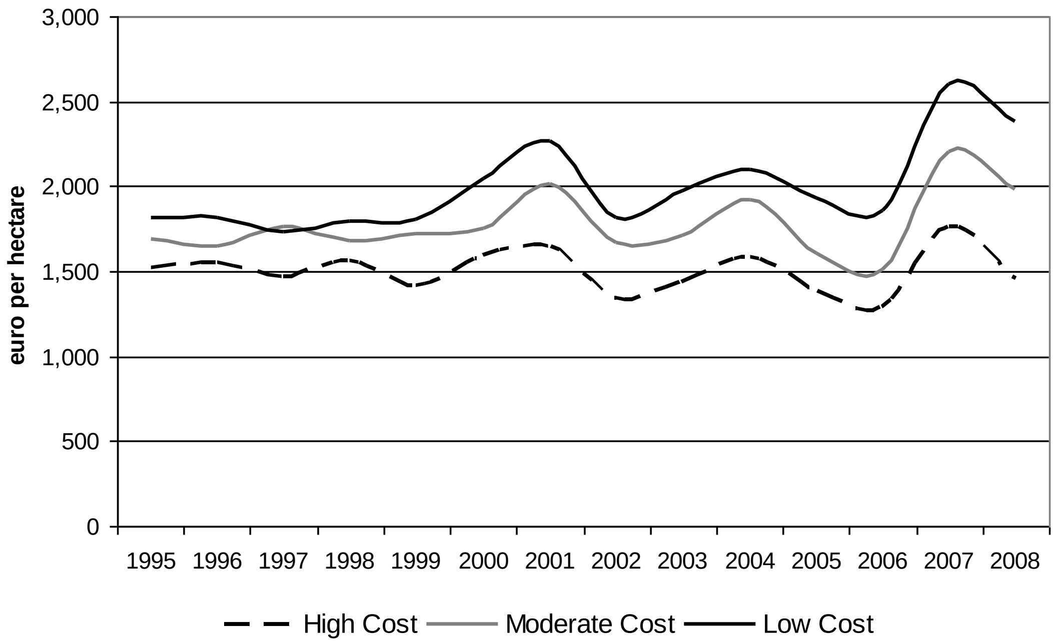
Plotting the same data on a per hectare basis puts structural change in sharper relief. Figure 2.15 illustrates the divergence of the three cost groups more clearly, and it can be seen that the point of separation went back to the late 1990's. The year 1997 was important, as there was a brief inversion of the low-cost and moderate-cost series. Querying the data reveals that this was due to changes in the dairy forage area amongst the two groups; the low-cost group increased dairy forage area whilst the moderate-cost group reduced dairy forage area at the same time. If low-cost producers expanded production through rental or purchase of land under the control of moderate-cost producers, then this would explain the movements in each cost groups' gross margin per hectare.

Figure 2.14 Gross margin by cost groupings (cent per litre)



Source: National Farm Survey

Figure 2.15 Gross margin by cost groupings (euro per hectare)



Source: National Farm Survey

Such a scenario would also have been invisible when looking at per litre measures, so it was also supported by Figure 2.14—where 1997 looked typical. Low-cost producers would then have made an investment in 1997 that put them on a different trend line through subsequent years.

2.5 Conclusions

This chapter has exposed the reader to various data, both aggregate and farm level, which provided context for the discussion and analysis in subsequent chapters. The government policies and regulations which have been most relevant to the dairy sector were also introduced. Milk quota dominated the policy landscape, but the general market protections that dairy enjoyed were also consequential, as was the regulatory framework of the Nitrates Directive.

The dairy sector in Ireland has been effectively constrained by milk quota in terms of output, but this has not resulted in a static sector. On the contrary, Specialist Dairy has consolidated (in terms of the number of farms) and intensified (in terms of yield per cow). Some evidence of efficiency improvements were suggested by the data. Fertiliser usage has decreased, possibly ameliorating a certain amount of over-application which has existed in the past. Veterinary expenses have increased, and this is a possible indication that AI and herd welfare measures have increasingly been adopted. In the chapters that follow, this thesis attempts to establish efficiency trends and their causes in a more statistically rigourous way.

Chapter 3 Development of a new data framework

3.1 Introduction

This thesis presents a series of quantitative analyses, all of which are concerned with the microeconomics of dairy production, and as such they require a lot of technical detail. The decomposition of TFP presented in Chapter 4 is particularly demanding; no dataset met the necessary criteria at the outset of this doctoral programme. This chapter provides some detail regarding the process of creating such a dataset. The derivation of the required variables is a critical step upon which research from the next chapter is built, so a thorough treatment here is necessary if the work is to be transparent and reproducible. Moreover, a detailed exposition supports the reader's understanding of the data in terms of its definitions and origins, and this is important for the correct interpretation of the various models which are estimated in the analytical chapters.

The chapter is structured as follows; the next section gives the requirements the data must meet in order to address this thesis' research questions. Section 3.3 describes the two datasets which best fit these needs, i.e. the Farm Accountancy Data Network (FADN) data and the National Farm Survey (NFS) data. Section 3.4 explains that the NFS dataset that most researchers use is actually a set of variables which have been derived from 'raw' survey responses. That section provides an illustrative example of such a derivation and relates it to the structure of code files which were designed to carry out the task. Section 3.5 describes the process of recovering sample weights from archived NFS Annual Reports. Section 3.6 calculates descriptive statistics and trends using the newly restored historical data. Section 3.7 closes out the chapter with a discussion of the implications of this contribution to agricultural research.

3.2 Data requirements

This section details the necessary properties which a dataset must possess in order to address the research questions analysed in this thesis. Firstly, the availability of reliable micro-level data is of critical importance. Aggregate data are not suitable to address farm level effects, as there is considerable heterogeneity in the population of Irish farms. This is true even in the dairy sector, which is commonly seen as the most commercially orientated of all Irish agricultural sectors, and which is also more homogenous than, e.g., the beef sector. Moreover, most of the subsequent chapters are dedicated to examinations of data and effects below even this level, i.e. the dairy enterprise within the sample of farms, so aggregate data would be even less appropriate than they would be in a whole-farm-level analysis.

This is not to say that aggregates have no place in this work. High level aggregates were sourced from the Central Statistics Office (of Ireland) and Eurostat. These data are representative of agricultural sectors as whole units or systems, rather than the individual farms of which they are composed. Such aggregate data were used to supplement the descriptive analysis in Chapter 2; to provide price proxies in Chapter 6; and to deflate certain monetised aggregates of capital formation and variable costs in Chapter 4. However, these can best be described as playing a supporting role, whereas the main weight of the work is shouldered by farm-level datasets.

The structure of the data is as important as its measurement level for the modelling conducted in this thesis. Special procedures are required in order to tease out causal relationships amongst the many (possibly spurious) correlations that exist in any observational dataset. Of chief concern are the various forms of unobserved variable bias which can enter into such an analysis. Although there are methods to account for these biases in a cross-sectional context, the availability of panel data—that is data which tracks individual farms over multiple years—vastly increases the number and the power of econometric methods which are available to the researcher. Therefore, a dataset which has a panel structure is highly desirable.

Given that this research centres on questions of production, a dataset which measures technical variables along with farm accounts is valuable. Physical measures of input and output quantities remove significant complications in the modelling of production relationships as the variables are real, i.e. their units of measurement are unaffected by price changes[3]. Although the responses of both input usage and output supply are functions of such price movements, the mechanism which dictates this relationship is an economic one. Real variables allow a simpler estimation of production functions, where the correspondences between inputs and outputs are not economic but technical, and therefore should not depend on prices.

All the foregoing requirements are common to many microeconometric studies, but this thesis adds another stipulation in its focus on milk quota policy. Questions concerning milk quota policy will need many years of data due to the many changes the policy has undergone over the years. Furthermore, individual years can be anomalous for a variety of reasons, e.g. weather, policy changes, macroeconomic developments unrelated to agriculture, etc. It is therefore of paramount importance that the data contain many years worth of observations.

This need is even more evident in Chapter 4 which aims to provide a unique value to the literature via the duration of the analysis. The TFP series generated therein not only

[3] If the inputs and outputs measured are homogeneous or assumed to be homogeneous

draws on microeconometric methods to decompose the series, but it does so for a 34-year period which extends as far back as 1979, i.e. five years before quota policy was implemented across the EU. Such a data requirement is rarely met in microeconometric studies; even some macroeconomic aggregates do not go as far back, and many of those that do provide only multi-annual data points. This work demands many variables of a granular level of technical detail, and which must have reliably annual reporting.

If technical aspects of the sample design change too frequently or unpredictably, then the researcher cannot draw conclusions from that data with any confidence. Therefore, the data must also represent a consistent framework of variable definitions. Without this requirement, there is little hope of drawing useful inferences about the population of dairy farms over so long a timeframe.

3.3 Sources of data

This section describes the two main sources of Irish agricultural data which provide most of the desirable traits described above; these are the NFS dataset and the FADN dataset which contains contributions from all the EU MS. Both are employed at various points in this thesis, and the two are related; a subset of the NFS data is that which is provided to the FADN by Teagasc every year.

The FADN has a relative strength in work involving international comparisons, whereas the NFS is a richer data source making it the natural choice for analyses which are concerned with Irish data alone. The data sources and their differences are more fully explained in the next subsections.

The Farm Accountancy Data Network

The analyses presented in Chapter 5 and in Chapter 6 are conducted on the basis of panel data provided by the FADN. The aim of the network is to gather accountancy data from farms for the determination of incomes and business analysis of agricultural holdings. The network consists of an annual survey, which is derived from national surveys carried out in the Member States.

The FADN liaison agencies collect accountancy data from a stratified random sample of farms in a highly professional and standardised way. These data form an (unbalanced) panel of repeated observations over time. The sampling methodology ensures that the data will be representative across systems, geographic space, and economic size. A crucial benefit of this dataset is the imposition of common accounting treatment for its variables. This harmonisation allows for comparisons of statistics across regions and farming systems.

The FADN is the only source of microeconomic data that is harmonised, i.e. the bookkeeping principles are the same in all the countries. This is one way in which the FADN data adds value beyond the NFS data—or equally other primary data from liaison agencies—which underpins them. The researcher can have greater confidence in the validity of comparisons across EU MSs—or even disparate regions of MSs—insofar as these comparisons are essentially valid. The FADN data cannot rectify fundamental differences across MSs and regions, but comparisons that are supported by technical knowledge of agronomy and systems will not be spoilt by inconsistencies in data treatments.

Another benefit of the FADN data is that all of its variables are measured in a common currency, i.e. in term of euro. At first glance this may appear to remove the need for exchange rate considerations, but the methods from Chapter 5 show this not to be the case when there are large exchange rate movements between a national currency and euro. If the object of the analysis is a comparison of production systems, and if exchange rates are not consequential for farm production decisions, then merely stating nominal measures of input and output in euro terms can distort the results. Special measures were taken in Chapter 5 to remove this ‘lensing’ effect from the data before any further analysis was undertaken.

The National Farm Survey

The NFS data provides an unbalanced panel of ‘commercial’ farms, i.e. those farms which are above a certain threshold of economic size. The survey is conducted annually by Teagasc, the Food and Agriculture Authority of Ireland. Participation in the survey is voluntary.

The survey yields a high quality micro-level dataset with measures of economic, sociographic, and technical variables. The responses are collected during an interview between professional farm recorders and a member of the farm household. Indeed, it is often the case that farm accounting documents are consulted during the interview.

Teagasc attempts to collect data from the same farms over multiple years. However, the voluntary nature of the survey means that some farms will inevitably end their participation early, either due to unwillingness or inability to provide data (e.g. a farm may cease operation in a particular year). In addition, the NFS is periodically resampled so that an entirely new panel is selected from the sample frame[4], although the same farms can be sampled again. These facts lead to panel data which is highly unbalanced. Farms typically provide data for only a few years before exiting the sample. However, there are no adverse effects from the unbalanced nature of the survey to either the statistics generated from it or models estimated using its data.

One weakness that the survey design does present is that it creates difficulty in determining levels of farm exit; a discontinuation of data from a particular farm may indicate an end of its operations altogether, but it may also be that it just ended its participation in the survey. Thus, analyses of farm exit from agriculture are made extremely difficult, although exit from a particular system of farming (e.g. specialist dairy) may still be possible if enough farms happen to make such a change whilst continuing to provide data to the survey under their new classification. However, the complications arising around this point make such an analysis beyond the scope of this thesis.

The data contain observations recorded from as long ago as 1979 and as recently as 2012. However, although the survey has collected these responses, it is only as a result of recent efforts that the data has become usable on modern machines and the most common statistical software packages. Further details regarding this effort are given in the later sections of this chapter.

[4] The sample frame is a subset of the entire population of farms. Details are provided in the appendix.

Comparisons of the NFS and the FADN

In the case of Ireland, Teagasc is the national liaison for the FADN, and hence it is the NFS dataset which is sent to the FADN after any modifications necessary to harmonise the data with the rest of the network. Such alterations are typically small; the NFS methodology is very close to the FADN's. There are some differences however, e.g. in the treatment of timing of payments and for which year such payments may be included in farm incomes. Another example is the treatment of depreciation of assets. These methodological differences are not consequential for the analyses carried out in subsequent chapters.

There are two differences between the NFS and the FADN versions of Irish data which are important to note however. The first is that the FADN, being harmonised across several EU MSs, will necessarily have only a subset of the variables which are available for the NFS, as the latter is a particularly rich data source. This somewhat constricts the modelling done in Chapter 5 and Chapter 6, both of which are based on EU-wide FADN data. In particular, many of the socio-demographic data that are available in the NFS do not exist in the FADN.

The second important difference is the time horizon of the particular FADN dataset was made available to the author[5] The fact that the FADN data dated back to only 1999 made the analysis carried out in Chapter 4 using NFS data impossible to reproduce in a FADN context.

Ultimately, the FADN data are more suited to inter-country comparative analyses than are the NFS data, and these were the data chosen for portions of the thesis which

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[5] The entire FADN dataset is very large. Researchers typically work with subsets of the database which are relevant to their studies, and for which a formal request to the FADN must be made.

undertook such cross-country work. On the other hand study of Irish TFP development did not require a harmonised dataset because it was contained within Ireland, so the strengths of the NFS made it the natural choice for this portion of the work. However, the time horizon needed to be extended backwards from the mid-1990's, providing the impetus for a significant contribution to an ongoing data project within Teagasc.

Two specific tasks were accomplished by the author. One was the adaptation of existing code to allow for the calculation of derived variables, i.e. the measures which are typically of interest. This was accomplished despite differences in the format and definitions of the 'raw' data for the years pre-dating 1984. Minor additions were also made to the post-1984 calculations, e.g. to derive specific variables for which code had yet to be written. The other task was the recalculation of the sample weights which are necessary to generate representative statistics from the post-1984 data. Details concerning both of these tasks follow below.

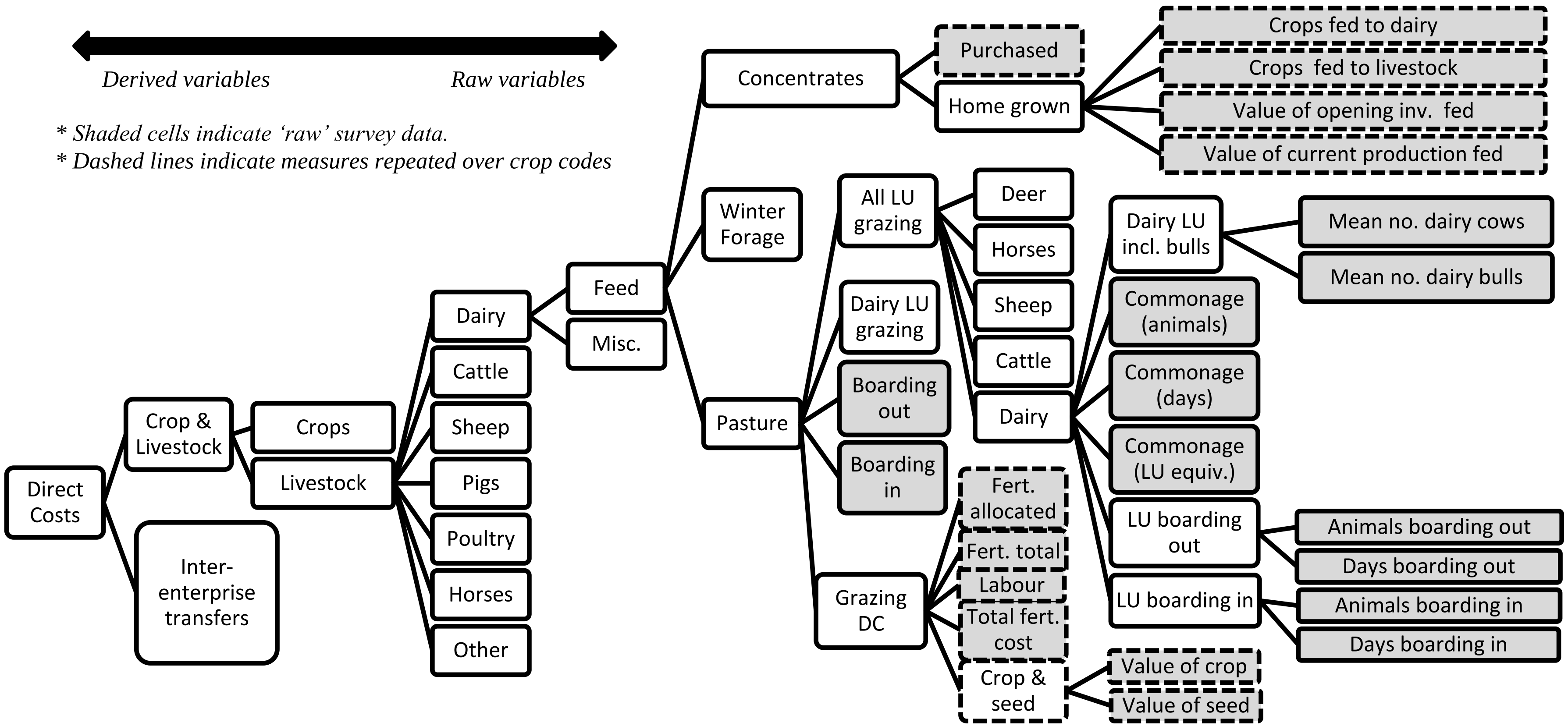
3.4 Deriving the NFS

Possession of the 'raw' NFS data alone does not allow any of the econometric research which is most typically carried out using this data source. In this section, light is shed on the general differences between the 'raw' NFS and the 'derived' NFS which is used most often for research. Definitions of some high level variables are given as examples of the types of accounting identities which must be satisfied. These definitions are related to the code framework which was employed to accomplish the variable derivations, and a brief discussion of the structure of files and data storage is also provided in this section.

As stated above, the NFS is collected on farms via a professional Farm Recorder using a standard ‘Farm Recorder Book’. The responses on this form are stored in a database, and the entire compilation of these data points makes up the ‘raw’ NFS. Most NFS variables which are ever the subject of any analysis have been carefully ‘derived’ from this ‘raw’ data in a multi-step calculation process; relatively few ‘raw’ variables are ever cited in any published source.

Variable derivation involves the application of simple accounting identities. Although these identities are straightforward, both the large number of them and the interconnections between them introduce considerable complexity into the process. For example, a partial derivation of whole farm Direct Cost is illustrated in Figure 3.1.

Figure 3.1 Partial derivation of whole farm direct costs



Source: National Farm Survey (Author's illustration)

The schematic given above represents a partial derivation of whole farm direct costs. It traces the path through two components of dairy feed costs all the way down to the complete set of raw variables which they require. These variables are shaded in the graphic, whereas the remaining cells all indicate a variable which is derived from some combination of raw variables. The chart is arranged such that raw variables tend to appear towards the extreme right of the graphic, and as one scans to the left the variables become increasing complex in terms of the number of calculations require to derive them.

The detail presented in this illustration gives the reader some sense of the intricacies involved in deriving the NFS. For example, there are at least four levels of variable derivations for the calculation of the dairy feed costs associated with pasture. This depth is due to the calculation of the number of grazing LU (1st level), which depends on the number of grazing LU in each livestock category (2nd level). The number of grazing dairy LU depends on the overall number of dairy LU (3rd level), which is calculated from 12-month averages of dairy cows and bulls (4th level). However, the reader cannot know if the calculation is deeper than four levels on the basis of the figure alone, because it does not depict any of the calculations for the grazing LU for other livestock categories, and there is no guarantee that the calculations exactly mirror the dairy calculation.

In truth, the real breadth and scope of the derivation of whole farm direct costs becomes apparent only when the reader considers what the graphic does not show explicitly. Scanning from right to left not only moves the reader from raw variables to increasingly derived ones, but also from variables whose calculations are fully depicted in the graphic to ones whose calculations are merely implied by it.

Consider again the variables involved deriving dairy costs associated with pasture. If one begins counting levels from the right to the left, i.e. from raw variables towards the derived variables, then the graphic is incomplete by the time one arrives at total grazing LU which is only two levels in. Each derived variable may be expanded to the point where the last calculation depends solely on raw variables, so the reader may imagine numerous additional nodes and trees representing these calculations.

However, there is even more which is alluded to in the graphic, and yet cannot be shown directly. The reader will notice several cells have a dashed border. This signifies raw variables which are specific to individual crops. Individual crops receive codes in the raw NFS, but most of these are seldom presented at the crop level in derived versions of the data. Instead, aggregates of several related crops are typically used, e.g. cereals. These cells imply an enumeration of—or a repeated calculation over—some collection of individual crop codes. This may be as simple as summing the measure over a list of relevant crop codes, but it can also be something more complex.

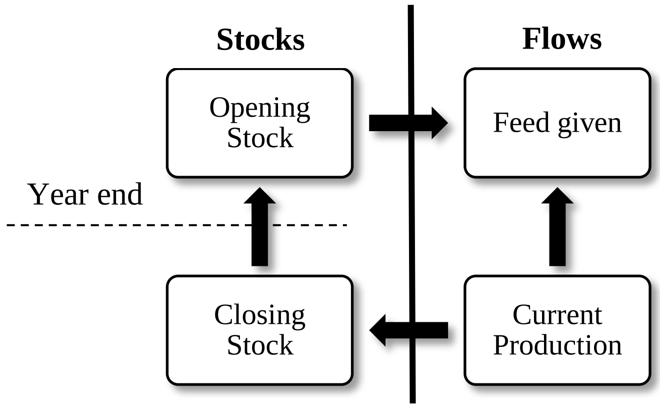
The point of the graphic is to impress upon the reader a sense of the number of calculations that can be involved in deriving the NFS, but it is beyond the scope of any single graphic—or even table of reasonable length—to depict all of these calculations in detail. However, a complete accounting is not necessary for the reader to be aware of the size of the task involved in deriving the NFS, as well as the interconnectedness of its many variables.

Stocks, flows and values

There is another level of detail which is only intimated by the graphic and which has yet to be discussed. Consider the variable in the extreme upper-right corner of Figure 3.1.

These variables are required for the calculation of home-grown feeds, i.e. crops which are fed to livestock. Note that grass products are classified as individual crops, i.e. hay and silage. The variables which measure the value of opening inventory and current production of these crops factor into the calculation. This demonstrates the treatment of stocks and flows in the NFS, and it is useful to consider it in the context of feed here.

Figure 3.2 Feed stocks and flows



Source: National Farm Survey (author's illustration)

Figure 3.2 details the treatment of stocks and flows in the NFS via the example of feed crops. A number of crops can be used either as feeds or as marketed as commodities themselves. Generally, there will be some stock of the previous year's production which was dedicated as a feed crop, and this will make up its opening stock.

The portion of the current year's production of crops which are devoted to feed are defined as the current production of the respective feed crops. Once opening stocks have been exhausted, the farm will start feeding from current feed crop production. Livestock will be fed these home-grown feeds throughout the year, but much of it is fed through the winter as the weather generally does not permit extended periods of grazing in this season. Any production which is not fed to livestock by the end of the current year makes up that year's closing inventories of the various feed crops which in turn become the following years' opening stocks.

For the purposes of modelling production, an oft used approach is to include measures of feed and fertiliser in the estimated production function. This seems at odds with the Figure 3.1, but recall that production functions take quantities as inputs and not the costs associated with them. When costs are included in a production function they are strictly meant as proxies for underlying input quantities. Nonetheless, the choice of fertiliser as an input is not directly implied by the diagram.

In the strictest sense, fertiliser is an input into a function which determines the quantity (and cost) of feed as defined above. Fertiliser helps determine grass and tillage output, which in turn will be divided into grazing and winter forage feed sources for the herd. If feed is defined to include all of these sources, then including fertiliser in a production function may be redundant, and yet models are often specified precisely this way.

The explanation lies in the fact that reliable estimates of grass quantities are often unavailable, so feed quantities really represent purchased feed only. Hence, fertiliser is often included as a proxy for grass production—inclusive of hay , silage, and grazing—in contexts where grass-based systems dominate. In systems where arable or tillage crops are an important feed source then the link to pasture production is less strong, but it still provides a good proxy for home-grown feed production.

There is a separate problem with the valuation of grass inputs, and therefore also in the value of home-grown feeds which depend on these costs. The reader will recall that the cost of home-grown feed is dependent on the values of opening stock and current production. However, there is a fundamental difference in the interpretation of these values when one considers forage crops as compared to commodity crops. For commodity crops such as cereals, the economic costs of feed can be derived using market prices because there are well developed markets for these products.

The same cannot be said for forage crops in Ireland. Although purchases of forage crops occur, these tend to be associated with short term supply shortages on the back of bad weather. This can be particularly acute if it occurs at the wrong time of year , as most silage production occurs in the autumn. Because the markets for forage crops are thin, and because decisions regarding forage production must be made well in advance, prices in such situations tend to inflate rapidly. Therefore, these prices do not present a reliable guide to the true opportunity cost of forage crops in normal circumstances, because the farmer will not be able to achieve this price if the crop is sold instead of being fed to livestock.

The NFS captures accounting costs, or ‘cash costs’ for these values. The value of unsold forage is not captured, and the researcher is left with only the cost of the inputs which generate forage production, i.e. mainly labour and fertiliser. This is appropriate for a cash cost analysis, but it does represent an uncounted cost in an economic analysis, i.e. the margin that would be attainable if the market for forage products were not so thin, or if there exist certain unmeasured transactions such as barter and private contracts. The assignment of an appropriate opportunity cost for this input is beyond the scope of this thesis, but the topic certainly warrants future research.

Operationalising variable derivations

This subsection relates the variable definitions and raw measures which are used to calculate them—as described in the previous section—to the structure of the data files which store the raw data, and the code files which carry out the calculations. A brief overview of the process is presented, as are some of the adaptations which are necessary to create a consistent data framework between the earliest years and the remaining panel.

The raw NFS data is stored in a system of database tables. These tables are fundamentally different from what most researchers have experience with as their dimensions vary depending on the variables contained within them. Many tables will be structured in the usual panel structure, i.e. a single row represents a farm-year, but several represent multiple observations from within each farm-year. These ‘multi-caret’ tables will have a separate code identifier included to note this additional dimension. In the example from the previous section, the relevant variables are stored in ‘crop tables’ whose identifier is a four-digit crop code.

The system which typically handles these databases uses the Xpath/Xquery database language. However, many statistical packages can handle the type of data merging that is required to arrive at a consistent panel using this data. The challenge presented by this structure is mainly due to the thousands of variables which would be created if all levels of every code identifier, e.g. crop codes, were given unique variables. Many of these variables would be mainly zero or missing values, and most would not be of direct interest to the researcher. It is precisely for these reasons that the data is structured as it is to begin with; the data represents an economical storage structure.

Therefore the approach taken is to iteratively merge the appropriate tables for the individual variables as they are derived. Although this entails repeatedly merging some tables, there are often groups of variables which can be derived together, so the overheads that are involved in terms of execution time are very reasonable. However, this does mean that the ordering of the merging is crucial, as variables will have their necessary components available at certain times only.

This differs from the typical situation whereby a variable may have a threshold for the earliest point at which it may be defined because some variable it depends on does not yet exist. In most instances there is no upper threshold for the latest point for such definitions because, once a variable is defined, then it continues to exist in the data until it is purposefully removed. In this case, the iterative merging procedure dictates that some variables will have a ‘window’ in which their components are available, and which is bounded on both sides.

Attempting to define a variable outside of this window will result in one of two outcomes; in the best case, an error is thrown which prevents the code from completing. In the worst case, a variable may be calculated incorrectly with no indication of the error. Therefore, it is absolutely critical that the researcher that edits this code understands the structure of the data in memory as each line executes.

In addition to understanding the structure of the data, the researcher needs to understand the structure and implementation of the code. Avoiding the mundane, a brief description of the overall approach is as follows. Firstly, the code is structured in two tiers; a main file and a number of supporting files which carry out specific tasks. The support files follow a naming convention which uses two-digit prefixes to indicate the purpose of the file. The prefix “Cr” indicates a typical variable definition file, and “PC” is reserved for price imputation specifically.

The main file itself is generally restricted to calling the support files: very little calculation actually occurs in the main file. The basic operation of the main file follows a pattern. First a list of variable names are enumerated in the code, and a loop will run over this list. The loop will handle the loading and merging of whatever data tables are needed for each variable specified in the list, and it will call the associated support file to actually calculate the derived variable. Multiple variable definitions may be contained in any of these individual files, thus cutting the number of iterations the loop must go through, repetitive lines of code, and unnecessary merging. The loop also contains a saving command to store whatever variables have been created before the next data table is loaded. Many of these saved datasets will be in the desired panel structure, but some are intermediate data files which are merged later.

This architecture had been developed previously, but some adaptation was required in order to include the earliest years of the data from 1979-1983, and supplementary code was required to prepare this data to allow the code to run at all. This code is available upon request from the author, but there are some main themes in this process which can be enumerated here.

Unlike the more recent data, the 1979-1983 data was contained in a collection of five spreadsheets, with each representing a year of data. The variables were spread across 70 individual sheets. These sheets represent the 'cards' which the data were originally recorded on, i.e. a section of the 'Farm Recorder Book'. The author mapped these sheets into the same structure of 31 data tables as the modern data, and these were saved as individual Stata datasets. In most instances the correspondence between a card and a table was 1:1 or 2:1, but in some instances individual variables from a particular card needed to be assigned to a different table than the other variables on that card.

Secondly, the author mapped default variable names—based on the header row of the spreadsheet when Stata originally imported the file—to the variable names used in the derivation code. The header names were generally descriptive enough to give a good sense of what each variable actually measured. This was done with the guidance of the Teagasc Research Officers whom currently handle the NFS data, and summary statistics were used to validate any variable for which the definition was unclear.

Finally, once the data were in the correct form to allow the derivation code to run, the code itself had to be adapted to account for fundamental differences in the data. Table 3.1 provides brief descriptions of some of these adaptations. There are a variety of changes that needed to be made, but most stem from the fact that the older data simply does not contain the same level of detail as the more recent data. In some instances categories of livestock were collapsed into an amalgam, e.g. some variables which are now collected by the sex of cattle are a single variable in the older data, and in other cases some data was not collected at all, e.g. many variables for deer and goats. The number of such changes led the author to create a copy of the code to run on the older data separately, thus leaving the existing code intact. This introduced the need for further minor adaptations such as correcting filepaths. The end result is a collection of data files which contain both raw and derived variables in the desired panel structure for both the pre-quota period and the subsequent period. These data are a consistent framework of variable definitions and measures, and they can be merged to form a single long panel.

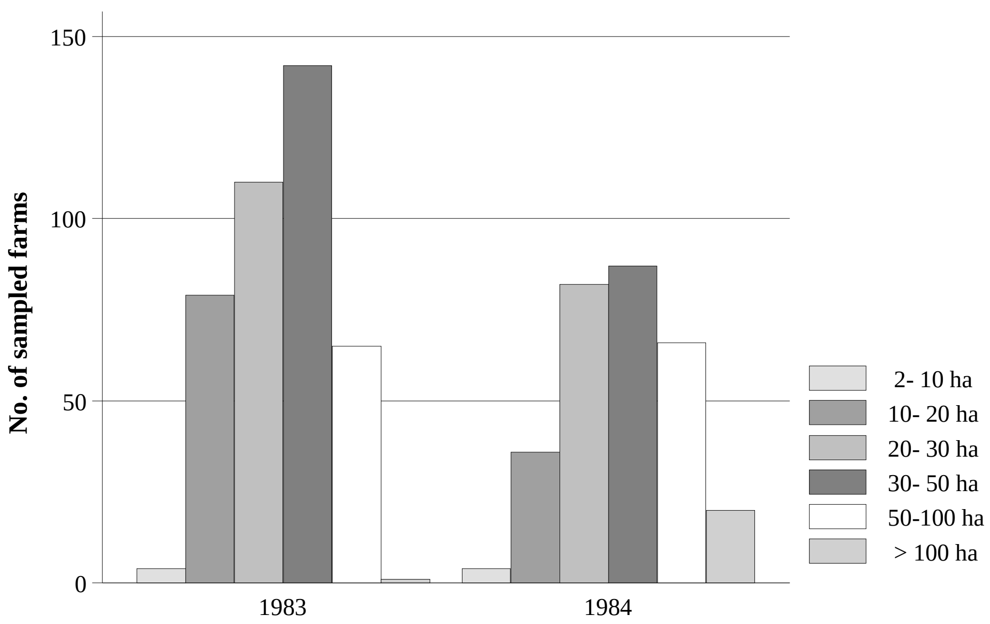
Table 3.1 Examples of code adaptations necessary for the years 1979-1983

Cr_OP_INV_VAL_EU.do|79 col 3| * CHANGE-7983	rename Stata derived var (no sys. var to test against)
Cr_d_conc_fed_cattle_eu.do|8 col 3| * CHANGE-7983	Hard coded filepath
Cr_i_concentrates.do|32 col 3| * CHANGE-7983	rename Stata derived var (no sys. var to test against)
Cr_merged_crop_tables_2.do|16 col 3| * CHANGE-7983	rename Stata derived var (no sys. var to test against)
Cr_svy_cattle_0.do|7 col 3| * CHANGE-7983	create 0 variables
Cr_svy_dairy_produce_1.do|5 col 3| * CHANGE-7983	create 0 variables
Cr_svy_dairy_produce_1.do|33 col 3| * CHANGE-7983	leave d_milk_fed_to_livestock_eu = 0 (no vars)
Cr_svy_pigs_1.do|7 col 3| * CHANGE-7983	+ CULL_SOWS_BOARS_SALES_EU removed from formula
Cr_svy_pigs_1.do|17 col 3| * CHANGE-7983	Corrected formula for Pigs (received from B. Moran)
Cr_svy_poultry_1.do|5 col 3| * CHANGE-7983	don't have D_SALES_LIVESTOCK_PROD_EGGS_EU (no rename)
Cr_svy_sheep_0.do|13 col 3| * CHANGE-7983	no D_SLS_SHEP_ONLY_INCL_HSE_CONS_EU (no rename)
PS_Milk.do|104 col 3| * CHANGE-7983	added capture to following two tabstats
PS_PriceOnly.do|92 col 11| * CHANGE-7983	added capture to following two tabstats
PriceSimulation.do|376 col 3| * CHANGE-7983	don't replace s_b_ALLOC_*_test2 for DEER & GOATS
PriceSimulation.do|380 col 3| * CHANGE-7983	remove s_b_ALLOC_DEER_EU s_b_ALLOC_GOATS_EU from keep
mainPRG.do|475 col 3| * CHANGE-7983	removed from svy_deer_1 vlist3a
mainPRG.do|480 col 3| * CHANGE-7983	svy_subsidies_grants_1 removed from vlist6 (don't have it)
mainPRG.do|604 col 3| * CHANGE-7983	svy_horses_other_1_md was OrigData now OutData
mainPRG.do|719 col 3| * CHANGE-7983	removed s_b_ALLOC_DEER s_b_ALLOC_GOATS from prvlist4
mainPRG.do|915 col 3| * CHANGE-7983	removed d_deer_livestock_units from keep and gen
mainPRG.do|1975 col 3| * CHANGE-7983	don't merge fed_deer_tonnes or fed_goat_tonnes
mainPRG.do|1983 col 3| * CHANGE-7983	leave d_deer_winter_forage = 0
mainPRG.do|2317 col 3| * CHANGE-7983	don't use svy_deer, just set d_other_ GO to 0 and leave it

3.5 Concerning sample weights

In addition to milk quotas, the year 1984 brought with it a substantial methodological change in the collection of farm data by the NFS, and details of this change are given in this section. In the years prior to 1984, the national representativeness of the sample was accomplished by continuing the selection of farms until the sample resembled a scaled version of the farming population in terms of the desired criterion (of which size and

Figure 3.3 NFS sample distributions of farm size strata, 1983-1984



Source: National Farm Survey

system were a part). From 1984 onwards, the sampling procedure was brought in line with the EU methodology which underpins the FADN data, and in a similar way the national representativeness of the sample was accomplished through a weighting scheme.

The effects of this change can be seen in the size distributions of the sample in the years surrounding the change, as illustrated in Figure 3.3. This difference in the composition of the sample will sometimes affect the distributions of variables of interest, i.e. mean values will be skewed if the variables vary appreciably and systematically across the size distribution of farms

Calculating the weights

Although weights were employed in the sample methodology as early as 1984, digitally restored copies of the historical microdata did not retain this variable for any year before 1995. Furthermore, no known published records of these historical coefficients exist.

The lack of weights has a practical significance for this research, as they are required for data validation purposes. As stated above, the NFS data that appears in the research literature is a collection of variables which have been derived from questionnaire responses. The only way to be assured of the accuracy of this work is to check calculated summary statistics against their published counterparts in archived copies of the NFS Annual Reports.

The NFS has published annual reports throughout the entire time horizon covered in this thesis. These reports were an invaluable tool for validating the veracity of the derived variables, but from 1984 on these could only be used if weights were made available. Therefore, the reconstruction of these weights was critical.

Table 3.2 Sample Representation for reported Results (1995)

	Size(Ha)					
	<10	10-20	20-30	30-50	50-100	>100
Dairying	177	144	91	91	77	40
Dairying/Other	827	268	153	74	61	33
Cattle Rearing	350	145	176	65	37	0
Cattle Other	384	212	174	116	69	54
Mainly Sheep	381	174	119	58	45	26
Tillage Systems	344	98	79	65	46	30

Source: Author's calculations based on data published in NFS Annual Report 1995

The weighting scheme employed by the NFS relates sampled farms to a ratio of similar farms in the overall sampling frame obtained from the CSO. The 'rates of representation' provided in Appendix B of the more recent NFS reports (Hennessy et al., 2012) are the weights in question, and can be thought of as the number of repeated observations represented by each sampled farm. The weights are applied to each observation in the data, but they are defined over 'cells' to which the rows of data belong. The cells are just size categories interacted with farm systems, e.g. Specialist Dairy farms below 10 hectares belong to the upper left cell.

The equations below describe the calculation of the weights for sample cell c in year t. The left hand term $w_{c,t}$ is the weight, $n_{c,t}$ is the number of sampled farms in the cell, and $N_{c,t}$ is the population farms to be represented in that cell. The second equation (3.2) decomposes $N_{c,t}$ into the estimated proportion term $e_{c,t}$ and the total number of farms represented by the sample in year t with term N_t, which does not change across cells.

$$w_{c,t} = \frac{N_{c,t}}{n_{c,t}} \tag{3.1}$$

$$N_{c,t} = e_{c,t} * N_t \tag{3.2}$$

Actual numbers of sample farms are published alongside the weights in the same table in Appendix B of the NFS report. The 'estimated population distribution' is also available as a table (ibid.), as is the number of farms represented by the sample (in the text). The sampled farms, population estimates, and farms represented are the necessary and sufficient information for the calculation of the weights per (3.1) and (3.2) above. However, the tables in Appendix B were only introduced in recent years for which sample were already available. The rest of the data were more difficult to source.

The sampling frame (N_t) enumerates only those farms in operation in the country which are above the minimum size limit in operation that year, so estimates of the total number of farms from the CSO would not have been appropriate. In most years' NFS reports, this number of farms represented was quoted either in tables or in the text. Similarly, the number of sampled farms ($n_{c,t}$) and the population estimates ($e_{c,t}$) were also available for most years' NFS reports. These data were spread across numerous tables, and at times moved from one table to another as the formats of the reports

Table 3.3 Locations of sampling information in NFS reports

	Estimated Farm Population Distribution	Sample Numbers for reported Results	Sample frame
1984	Table 58	Table 1	195000
1985	Table 58	Table 1	193700*
1986	Table 58	Table 1	192400
1987	Table 58	Table 1	188300
1988	Table 58	Table 1	184400
1989	Table 58	Table 1	184700
1990	Table 58	Table 1	184000
1991	Table 32 - 37a	(counts of sample farms)	160000
1992	(weights carried forward)	(weights carried forward)	160000
1993	Table 23a-28a	(counts of sample farms)	157590*
1994	App. B, Table A	App. B, Table B	155180**

Source: NFS Annual Reports (1984-1994)
** Value imputed as a straight-line average of surrounding years*
** Value imputed on the basis of information contained in Table B*

changed over the years. Table 3.3 lists the locations of these tables over the years, as well as any imputations which were necessary when data were not available. Figure 3.4 is an image of a table from one of the actual reports.

Table 3.3 shows that some data limitations were present in the years from 1991-1993. In 1991 and in 1993 estimates of the proportions of the farm population belonging to each cell were available, but numbers of farms actually present in the sample were not. In these instances farm counts from the micro-data were used. Neither farm proportions or sample farms were available in 1992, so there was no alternative but to carry forward weights from the previous year.

Figure 3.4Table from historical NFS Annual Report

2.20

DISTRIBUTION (%) of FARMS
by SYSTEM OF FARMING and FARM SIZE

TABLE - 58 - 1985

ALL FARMS -- IRELAND

System	Dairying	Cattle	Dairying /Cattle	Mainly Sheep	Dairying /Tillage	Drystock /Tillage	Field Crops	Other Systems	All Systems
Size U.A.A.(ha.)									
2-< 10	2.6	12.4	2.0	1.2	0.0	0.5	0.3	0.0	19.1
10-< 20	7.5	13.8	3.3	1.7	0.0	0.7	0.3	0.0	27.4
20-< 30	5.6	4.6	2.7	1.3	0.1	0.6	0.5	0.0	15.5
30-< 50	4.6	4.0	2.5	0.8	0.0	1.1	0.4	0.0	13.5
50-<100	1.7	1.5	1.4	0.6	0.2	0.7	0.7	0.0	6.9
=>100	0.1	0.3	0.2	0.1	0.0	0.3	0.3	0.0	1.3
Hill Farms	0.3	10.1	0.3	4.8	0.0	0.3	0.0	0.0	15.8
Other Systems	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
All Farms	22.5	46.6	12.5	10.6	0.4	4.3	2.6	0.5	100.0

LE - 59 - 1985

Source: NFS Annual Report 1985

The raw data also lacks any variable that classifies the farms into the systems that partially define the sample cells. The calculation of the system definitions follow the European Community (EC) methodology and is quite complex. The same computer code which automatically carries out this calculation was run on the historical data to arrive at a system variable, but this imposes modern system definitions on the historical data. Therefore, any system whose definition changed over time would have the wrong farms assigned to it, and the misclassified farms would also have the wrong weights assigned to them.

Table 3.4 gives an overview of the system definition changes; Cattle is split into two categories, the Tillage systems collapse into one, and some farms move to Mixed Livestock. Fortunately, Specialist Dairy has had no such definitional change in the entire time horizon of the data, so it was possible to validate several high level variables against published series.

Table 3.4 Re-organisation of non-dairy and mixed farm types

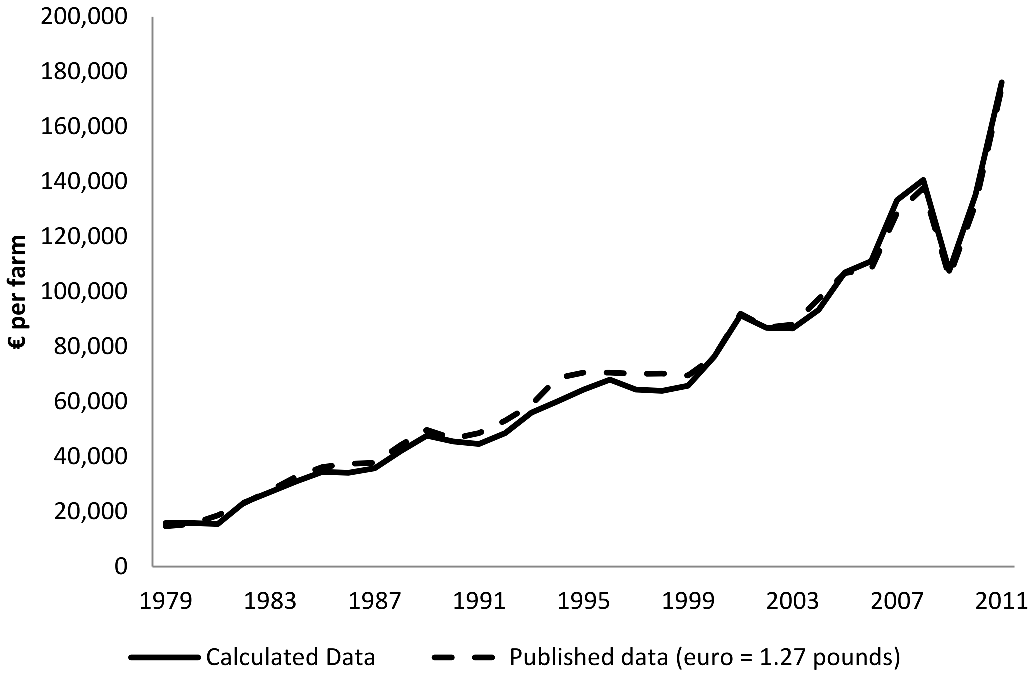
Historical (1984 – 1993)	Modern (1993 – present)
Dairying	Dairying
Dairying/Cattle	Mixed Livestock
Cattle	Cattle Rearing Cattle Other
Mainly Sheep	Mainly Sheep
Dairying/Tillage Drystock/Tillage Field Crops	Tillage Systems
Other Systems	

Source: NFS Annual Reports (various years)

3.6 Validation and historical series

This section provides some validation of the data derivations described above. Plots of three calculated NFS variables against their published series are provided below in Figure 3.5, Figure 3.6, and Figure 3.7. The choice of variables is not arbitrary; these high-level variables require literally hundreds of variables to calculate them, many of which are derived themselves. If these variables are close to the mark, then there should be a high degree of confidence that most variables have been derived correctly, as any large mistakes would also manifest themselves here.

Figure 3.5 Validation of mean whole-farm gross output, Specialist Dairy



A visual inspection of the figures implies that the calculated weights and the variable derivations are very close to previously published data. The relationship is very tight throughout the panel, although there is some loosening in the mid-1990's. However, the period post-1995 contains the original weights, i.e. these were not changed, so the small difference that does exist for this period is likely due to small changes in sample selection at the researcher level, i.e. the decision rules for which rows of the data to include. There are also occasional revisions to either published data, or the microdata itself as these become necessary, and these might also play a role here.

The average whole-farm gross output registers no obvious ill-effect around the time of milk quota implementation; the average value is always growing, but the reader is cautioned that this is a nominal series, and it's primary value is for the validation of the data derivation and weight calculations. The relationships are equally as good for direct costs and overhead costs.

Figure 3.6 Validation of mean whole-farm direct costs, Specialist Dairy

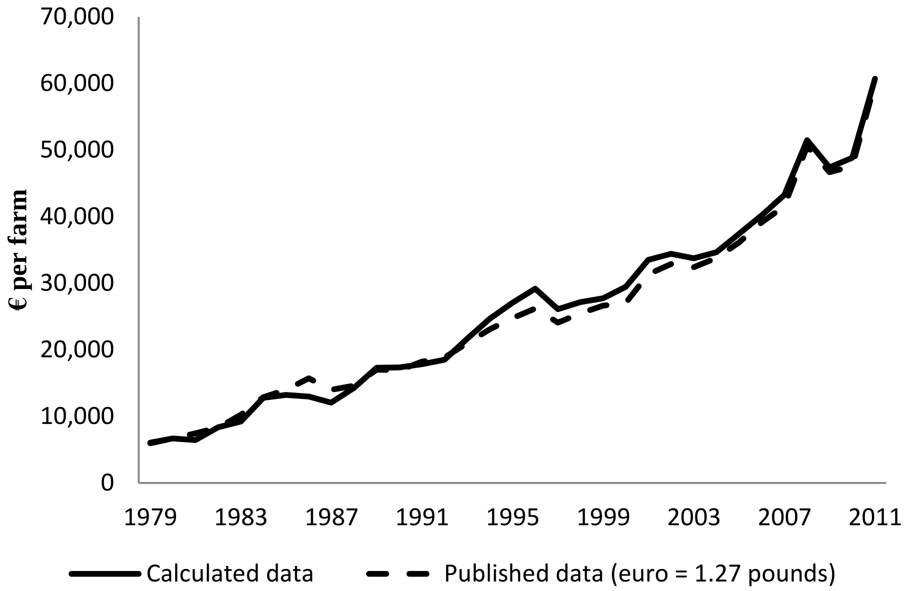
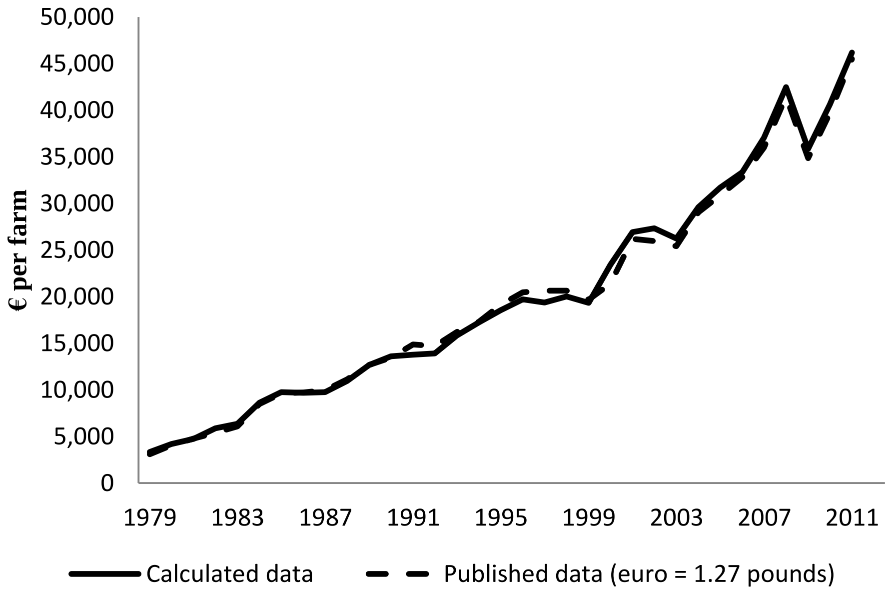


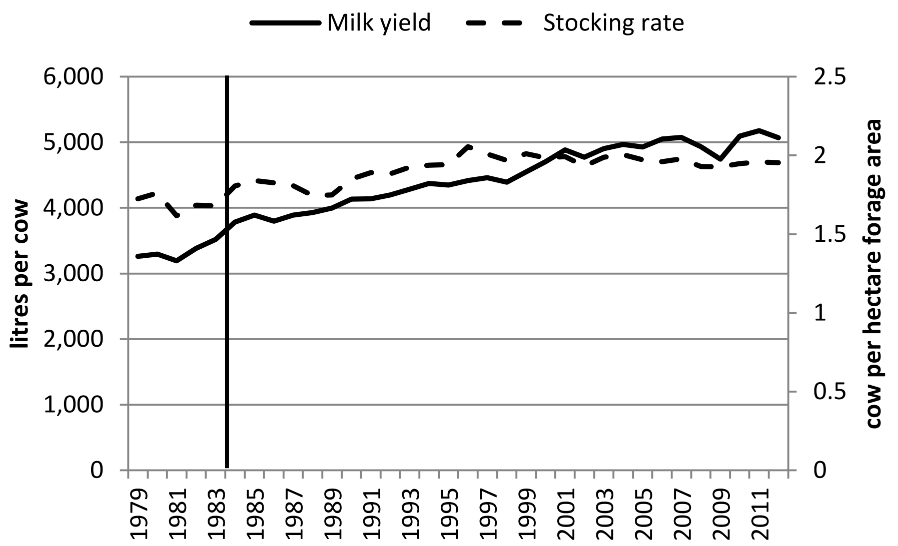
Figure 3.7 Validation of mean whole-farm overhead costs, Specialist Dairy



The data shown above are all in nominal terms, albeit using a constant conversion rate of 1.27 pounds per Euro. More informative series come in the form of real variables, either physical quantities, deflated series, or ratios of variables. Such series will be shown below, and these will be followed by hypothesis tests of their means and standard deviations.

Figure 4.1 gives the trends in two ratios which represent a decomposition of gross output per hectare, i.e. milk yield and stocking rates. As can be seen from the graphic, and as mentioned above, the stocking rate is initially on a positive trend until it reaches a peak in the late 1990's at which point it halts at essentially the same level as the most recent year of the data. It is possible that these are the effects of the Water Framework Directive—which was to be enacted in 2000—and the Nitrates Directive—which was already in the legislation. These environmental limits put a cap on potential stocking rates.

Figure 3.8 Trends in stocking and yield



Source: National Farm Survey (author's calculations)

The milk yield as measured in physical terms progresses more quickly than it did in terms of real euro. The latter reflects softening milk prices and the effects of inflation, but those are not present here. This series underscores the importance of milk yield as a driver of profitability. It is notable that—unlike the partial productivity indicators given in Figure 4.1—there was no apparent effect on either milk yield or stocking rates as the milk quota became a reality.

Figure 3.3 illustrated the effects of the change in sampling methodology on the distributions of farms over the size strata between 1983 and 1984. This change suggests that there may be a effect on sample means and variances around 1984.

Table 3.5 Tests for equivalence of means and variances

	Means		Variances	
	t-stat	p-value	f-stat	p-value
€output/cow	-25.314	0.000	145.685	0.000
€output/ha	-18.320	0.000	170.619	0.000
€output/hour	-20.335	0.000	237.000	0.000
€output/€direct cost	13.617	0.000	48.540	0.000
€output/€investment	-0.07	0.942	0.052	0.819
Milk yield	-19.676	0.000	73.147	0.000
Stocking rate	-6.582	0.000	0.177	0.674

Table 3.5 displays the results of hypothesis tests of these parameters. The test of means is a t-test—with or without the assumption of equal variances as appropriate—and the test of variances is Levene’s test, which yields an F-statistic. The tests were conducted on means and variances which were calculated for five-year periods before and after

1984, i.e. 1979-1983 and 1984-1988. It is apparent from the table that the hypothesis of equal means in these two sub-panels is rejected for all the variables bar the productivity of capital investment. This is not especially surprising, as these series are all developing over time. However, all but two variables also reject the hypothesis of equal variance over the sub-panels, indicating that the sampling methodology may have an effect on any estimated models and thus should be controlled for.

3.7 Concluding comments

The preceding discussion has demonstrated the value of the National Farm Survey. The dataset it provides gives an unparalleled view into the decision processes of Irish farmers through its wealth of variables. The data provides socio-demographic data alongside farm accounts and some of the most detailed agricultural production information one is likely to find. The value this dataset brings to the community of agricultural researchers, policy makers, and industrial stakeholders is obvious.

The NFS data plays a critical role in crafting policy which affects not only agriculture, but the entire Irish economy. Whilst it is true that agriculture generally becomes a smaller share of an economy’s gross national product as it develops, this is more a measure of the security which a mature food production system provides the wider economy than of its significance to it; an adequate and secure food supply is a pre-requisite for economic growth. Furthermore, the agricultural sector in Ireland has led the way back from the economic collapse of 2008. These facts underscore agriculture’s relevance to the modern Irish economy, as well as the importance of the NFS data which is used to analyse it.

Of course, the NFS, being such a rich dataset, has always had the potential to contribute to the wider literature of production economics. A farm is just a special type of firm, so it is unsurprising that agricultural data has often been the medium for the advancement of microeconomic theory. Malthus' famous treatise on the limits to growth provides just one example.

This potential is greatly enhanced by the extension of the digitised NFS data to a period which is further back in time The NFS data has always had a key strength in the detail and quality of its measures, but now the capability to calculate long-term, farm-level measures has been added to this. It is now possible to observe farm level reactions to external stimuli—such as policy changes or macroeconomic developments—from as long ago as the start of the 1980's. Furthermore, this sort of data permits the study of distributions of variables of interest, e.g. farm incomes, which is a feat that cannot be duplicated using aggregate data.

This chapter describes the work undertaken by the author to bring the historical data into a format which permits easy manipulation using modern statistical software. Although the data were already in a digital format, these changes were labour-intensive, and they were not trivial. Researchers address difficult questions on short deadlines, and often with many different calls on their time. As a rule, data which is difficult to work with is generally under-used.

This work has brought the data to the researcher in a familiar structure—a block of panel data with each row representing a farm-year—and format-Stata data files or comma separated files. The need to learn a database language to manipulate the raw data has been removed, as has the need for an intricate knowledge of all of the accounting identities which generate the derived NFS. Furthermore, the researcher can be assured that the data represents a consistent framework of variable definitions, and can confidently generate statistics or estimate models using all of the data.

Obtaining this convenient format involved two major tasks; code had to be adapted to calculate the derived NFS for the initial years, and the system of weights which makes the sample representative had to be recovered.

The author was able to accomplish these tasks for the subset of Specialist Dairy farms in the course of this doctorate programme. Hence extended Specialist Dairy data is now available to those who have a need for it. Although validation of the resulting statistics is an on-going process, the plots of the most widely referenced high-level variables are reassuringly close to historically published results.

Further work is needed to complete the extension for the other farm types. However, bringing the other farm types along will be far less difficult than what is described here; weights and derived variables have already been calculated by the author, and all that remains is the correct assignment of farms to farm types. The chief obstacle here is the implementation of the EC farm typology which is very complex. The author has also developed the code to apply this typology, but some error exists which leads to the incorrect assignment of many farms, so this code is currently inactive. Once the error is discovered and corrected, the entire NFS will be available.

It will also be possible to use either the modern or the historical definitions of farm types for the purposes of modelling. To the best of the author's knowledge, this will be an entirely new capability for even the modern NFS. It will allow direct comparison to previously published data from before the implementation of the modern farm typology.

The final comments of this chapter acknowledge the many men and women who were involved in the resuscitation of the historical data before this final stage. The dataset would not exist if not for the work of the farm recorders whom collected the data originally and the many people whom handled the preservation of these records on computer punch cards initially, and subsequently on microfilm data tapes. Particularly large contributions were also made by Gerry Quinlan, who managed the retrieval and digitisation of the data stored on this analogue media; by Cathal O'Donoghue and John Lennon, who developed the original code for deriving the NFS for the period from 1984 onwards which was the basis for the author's adapted code for the previous years; and by Brian Moran and Anne Kinsella, who provided guidance with respect to the NFS and EC sample methodologies as well as access to invaluable historical documents. The significance of this accomplishment should be shared by all who were involved in its coming to pass.

Chapter 4 A dairy enterprise level TFP index

4.1 Introduction

The dairy sector across Europe is on the precipice of a post-quota era. A major production constraint will be lifted with milk quota's abolition in 2015; hence there is much interest in the policy from both an academic and from an industrial perspective. It is a good time to stand back from this policy—which has been an institution of European agriculture for 30 years—to assess its long term effects on production capacity. To this end, the present study examines trends in an index of Total Factor Productivity (TFP) constructed from a microeconometric model.

Much of the research attempting to forecast the EU response to quota abolition predicts a large expansion of Irish production (Binfield et al, 2008; Bouamra-Mechemache and Jongeneel, 2008; and Lips and Rieder, 2005). This result was of obvious relevance to other dairy exporting Member States, and indeed global participants in the milk trade. This expansion was already underway in milk quota's final year; average gross new investment per dairy farm stood at €19,558 in 2012, and this was more than double the figure for all farms at €8,173 (Teagasc, 2012). At the time of writing, dairy output was 6.9 percent over Ireland's final quota allocation, implying a substantial super levy in the policy's departing year.

It would appear then that Ireland was uniquely situated to take advantage of a post-quota era in milk production. Donnellan et al. (2009) found that Irish dairying enjoys a high degree of competitiveness owing to its low cost production system. This cost advantage was mainly driven by a comparative advantage in inexpensive grass inputs.

However, there were concerns over how the years of production constraints may have affected Ireland's competitiveness. The Donnellan et al. study itself notes that Ireland's cost advantage was significantly eroded if proper economic value was attributed to unpaid (mainly family) labour input. Irish production was also typified by sub-optimal scale and a low level of capital intensity which further damages international rankings. The Donnellan et al. paper also notes that competitor countries which have more liberalised quota trading systems tend also to do better in those aspects, although causality was not established.

Hennessy et al. (2009) constructed a linear programming model which quantifies the inefficiencies associated with the 'ring-fenced' design of Irish quota trade, itself in operation since only 2007/2008. Mathematical programming exercises of this sort were also employed in Kirke and Moss (1987), and later Colman (2000) regarding dairy production in Northern Ireland specifically in the former, and the United Kingdom more broadly in the latter. Colman et al. (2001) also give a good demonstration of an econometric approach using the specification of ad hoc cost functions. They use these estimates to simulate various changes to quota implementation, and to draw conclusions in relation to structural change and efficiency. All of these studies concluded that milk quota was associated with decreased efficiency, or that the distribution of quota was far from optimal with respect to an efficient allocation.

The studies discussed above are deeply rooted in standard microeconomic theory. This presents both strengths and weaknesses. Microeconomic theory is rigourous and internally consistent, but it requires strong assumptions regarding behaviour and the nature of production. Modern econometric analyses can relax some of these assumptions, and if the researcher chooses a stochastic frontier model, then some of these assumptions may be tested against the data.

Newman and Matthews (2006, 2007) provides a model paper for this analysis. They also chose SFA methods to construct TFP indices whilst specifically analysing Irish dairy farm data. They found that specialist dairy producers operate under a fundamentally different technology than non-specialists; there were higher rates of TFP growth amongst specialist dairy farms. The work presented in this chapter therefore focused on specialist dairy producers only.

Matthews also completed an earlier stochastic frontier study with O'Neill (2001) in which technical efficiency was measured, but no overall TFP index was calculated in that work. They too found that technical efficiency tended to be higher on dairy farms, but the analysis was flawed in that it assumed a common frontier for all systems of farming in Ireland, i.e. that a common technology was available to all farms.

Several studies of the Irish dairy productivity and efficiency have been carried out in recent history. Matthews (2000), Boyle (2004), and Donnellan et al (2009) invoke aggregate level approaches, whilst Newman and Matthews (2006, 2007), O'Neill and Matthews (2001), and O'Neill et al (2002) use micro level data. However, none have been able to use Irish farm level data going back before milk quota's implementation because these data have only recently been made available in digital format. The author's contribution to that data project—undertaken by Teagasc in recent years, and reviewed in the previous chapter—resulted in a dataset which is both consistent and representative for the entire period from 1979 to 2012. Hence it is now possible to observe the development of TFP and its components as the implementation of milk quota first took place in Ireland, thus the analysis in this chapter is the first of its kind.

The structure of the remainder of the chapter is as follows: Section 4.2 provides the theoretical framework which generate the hypotheses examined. Section 4.3 relays the methodology of the specific SF model estimated as well as the index of TFP calculated. Section 4.4 describes the panels constructed from the NFS data. Section 4.5 reports the model results and TFP index values, and section 0 draws conclusions.

4.2 Theory and Research Question

This section generates hypotheses of milk quota's effects on productivity after reviewing the relevant economic theory. These hypotheses are discussed in their own subsection at the end of this section.

Total factor productivity (TFP) finds its beginnings in growth theory. In a seminal paper, Solow (1957) described an aggregate production function which was Hicks-neutral, i.e. a shift in the function does not disturb marginal rates of substitution between inputs, but simply scaled the production by some multiplicative factor. Solow's original notation writes the function as

$$Q = A(t)f(K, L) \tag{4.1}$$

with $A(t)$ being that factor, which is today known as TFP. Solow then wrote a measure of growth in TFP which was the ratio of the time derivative of A to A itself, or $\dot{A}$/A. This has since been known as the Solow residual ($\mathfrak{R}$). These equations make clear that if TFP represents a type of 'speed' of an economy, then the Solow residual is a measure of the ‘acceleration’ of an economy, because it is the rate of change in TFP, i.e. its growth rate.

TFP is a fundamentally aggregate measure. It relates growth in output to growth in inputs for a sector, industry, or economy as a whole. Therefore, Solow’s approach is usually a macroeconomic undertaking; he advocated the use of factor shares for the estimation of the residual, and hence TFP. However, more recent approaches have also constructed TFP indices from elasticities which result from microeconometric models (Newman and Matthews 2006; Newman and Matthews 2007). The same approach is taken here, because it allows for weaker assumptions and it provides a method to break TFP into components of interest.

The Solow residual has historically been seen as a measure of technical change (TC), but this adopts the neoclassical assumption of fully efficient firms. If this assumption is weakened then technical change would only account for part of TFP, and changes in the levels of technical efficiency (TEC) then makes up another part. Further, decompositions are also possible. This chapter decomposes TFP into technical change, technical efficiency change, and scale efficiency change (SC), although other decompositions exist in the literature as well (e.g. Jeong and Townsend 2007).

Lastly, taking a microeconometric approach allows this analysis to provide extra value by identifying the trend in dairy enterprise TFP. As discussed in previous chapters, the dairy enterprise is a subset of the business operations of farms with dairy production. Even in the case of specialist dairying, some other enterprise will be present on these farms (e.g. beef). A microeconometric approach allows this chapter to address the effects of milk quotas on dairy productivity in a more specific sense than has ever been done in an Irish context previously. The following subsection develops hypothesised effect of milk quota from Solow's primary equation and from a profit function defined at the farm level.

Hypothesised effects of milk quotas on Irish dairy TFP

Any production function $f(x)$ which meets the usual regularity conditions should register a falling value as x decreases. Furthermore, if one makes explicit the fact that (4.1) is an aggregate production function by adding a subscript n and writing down the implied horizontal summation across firms, then one arrives at the following equation

$$Q = A(t)\left(\sum_{n=1}^{N} f^{n}(K^{n}, L^{n})\right) \tag{4.2}$$

which makes it apparent that falling numbers of farms (N) should have an adverse effect on output if $A \leq 1$.

Section 2.3 discussed trends in output and the processes of intensification and consolidation in the dairy sector. Output has remained at approximately the quota level of production over time, and this has varied in a fairly narrow band from 5.1 million tonnes to 5.7 million tonnes over the years. However, this output has been achieved via a decreasing number of farms (consolidation) and with a decreasing dairy herd size (intensification). Therefore, the term A above, which represents TFP must have been positive for at least the most recent years. The early years may well have been negative however, because quota introduced a new production constraint and because some portion of accumulated of capital would now be underused. To see this, simply place a bar over capital to signify that it is fixed in the short run.

$$Q = A(t)f(\overline{K}, L) \tag{4.3}$$

If K represents the most technically efficient level of capital in any given year, and if $\overline{K} > K$ in the years immediately after the introduction of milk quotas, then $f(\overline{K}, L) = f(K, L)$ and there is excess capital in the system.Since A relates changes in output to changes in inputs, and since $\overline{K}$ would be held essentially static immediately after quota owing to the asymmetry of investment and disinvestment, the reduction in output due to quotas would mean that A would have to be negative for some time until dairy farms adjusted.

Microeconomic theory may also be employed to predict several ways in which quota may have affected technical efficiency, and this will have had an effect on overall TFP. An understanding of these effects may be obtained via the use of a profit function.

Equation (4.4) is due to Guyomard et al. (1996) and it describes the profit relationship between a farm operating in a no quota production environment, and the same farm in a counterfactual situation of producing under a tradable quota system.

$$\begin{aligned} \Pi^{n}(p) &\geq \pi^{n}(p - r) + r\,\partial\pi^{n}(p - r) / \partial p \\ &= \pi^{n}(p - r) + r(\overline{y^{n}} + q^{t,n}) \\ &= \pi^{t,n}(p, \overline{y^{n}}, r) + rq^{t,n} \\ &\geq \pi^{t,n}(p, \overline{y^{n}}, r) \end{aligned} \tag{4.4}$$

Here p is output price, r is the rental rate of quota, $\overline{y^n}$ is the quota allocation specific to the farm and $q^{t,n}$ is the amount of quota rented (if positive) or leased (if negative). The immediately relevant term from this inequality is $rq^{t,n}$ which is the expense relating to obtaining quota. Several effects may now be hypothesised;

Farm entry and exit will have been reduced—Giving farms a legal right to produce on the basis of historical production prevents the imposition of market discipline, i.e. lowest cost (hence most profitable) producers cannot expand their market share at the expense of higher cost producers whom either choose not to sell, or else cannot sell because of restrictions on quota trade.

For a new entrant in a quota system, $\overline{y^n}$ is zero, hence the only production that can occur on entry is $q^{t,n}$. Therefore, $rq^{t,n}$ represents the effective barrier to entry presented by quota in this scenario. Actual barriers may be reduced by certain administrative allocations of quota, or may be higher in scenarios where quota is attached to land, both of which were the case for much of Ireland's experience of the policy. Furthermore, farms with a negative value for $q^{t,n}$ experience $rq^{t,n}$ as income. This income stream is lost if quota is permanently surrendered, hence the quota system also serves to disincentivise farm exit from dairying.

Sub-optimal scale—The situation faced by a new entrant is a special case of the situation faced by any expanding farm. By the same reasoning as above, $rq^{t,n}$ represents an additional cost for any expanding farm, hence fewer farms will expand, and those that do may expand by less than is optimal. So artificially restricting output has the effect of cementing under-scaled organisation of production. This also leads to the under-utilisation of capital mentioned in the macro-level discussion above. This particular effect should ostensibly have been quite pronounced in Ireland, as quota administrative policy has actively sought to preserve the number of farms in production rather than the efficiency of that production.

Uncertainty in production—farmers must make decisions regarding the buying of inputs and the setting of a target for output each year. Unlike most other industries, farm production is a biological process which has a high dependency on suitable weather conditions, so accurately predicting annual output with high precision presents quite a challenge. This is made all the more complicated by the existence of superlevies which will consume all profits from over-quota production without compensation for the inputs which were embodied therein. In the framework given above, this may be viewed as some quantity of quota q which must be rented from the body administering quota at a rate r which will be the fine for all of the overproduction. As a result, many farms do not fill their entire quota in any given year, and there will be some waste associated with this phenomenon. Some farms also take the gamble that the national quota will not be filled. In this case, unused quota is allocated to the over-quota production, thereby avoiding superlevies. This scenario rewards speculators, but these may or may not be the most efficient producers.

Disincentive to investment—related to sub-optimal scale and increased uncertainty, another way inefficiency may enter the system is through dissuading farmers from maintaining an adequate level of investment. According to Guyomard et al. (1996, p. 221), “[quotas] should be viewed as a capital asset in the same way as land or livestock.” Investments in quota therefore directly divert investment away from these other capital assets. Furthermore, quotas would indirectly dissuade investment through all of the effects discussed above. Sluggish investment both prevents the implementation of more efficient technologies, such as automated dairy parlours, and also results in the degradation of existing capital which requires a base level of maintenance.

Given the theoretical effects stated above, it was proposed that any TFP index which includes data from before and after the implementation of the milk quota in 1984 should register a disimprovment around this time. Furthermore, as quota became more freely traded, and in line with previous research on the topic, it was expected that TFP should improve, reflecting greater efficiency in the system. The components of TFP should point to the drivers of change in productivity. There was an a priori expectation that scale efficiency and technical efficiency would be negatively affected, although previous research shows that technical change tends to drive TFP both in Ireland, and in Europe more generally, so this was expected to be the most influential component. Furthermore, technical change was conceptualised as movements in the entire frontier over time. As quota was applicable to all producers, it was expected that technical change would register an adverse effect from the policy's implementation.

4.3 Methodology

The methods used in this chapter are set out in this section. A microeconometric method of constructing a TFP index is chosen; the main benefits of this approach include the relaxation of the assumption of efficient firms, and the ability to decompose the index. This still leaves a choice as to which econometric method to employ from amongst either SFA or DEA to estimate the necessary parameters. There are strengths and weaknesses to either approach, and a more detailed discussion follows in section 6.4. A SFA model was chosen for the purpose of this model; the main justification for this decision lies in the random nature of agricultural production (e.g. weather shocks) and the perverse affect this randomness may have on efficiency estimates.

The methodology followed in this analysis was very close to that in Newman and Matthews (2006). A stochastic frontier model was specified, the parameters of which were then used to construct a Generalised Malmquist index of Total Factor Productivity

(TFP). The index was then decomposed into three constituent parts á la Orea (2002), i.e. technical change, technical efficiency change, and scale effects.

Newman and Matthews specified a distance function in their work, but this analysis uses a production function approach instead. The main benefit of the former is that it accommodates multi-output production systems. This is a desirable property in a whole-farm model, given that Irish dairy farms are—without exception—multiple output production systems. However, this work aims to provide additional value to the literature through an enterprise level measure of TFP, so there was less need to accommodate non-milk sources of revenue which are minimal by comparison. Moreover, the difference may be purely semantic, as a single-output, output-orientated distance function has an econometric specification which is equivalent to a standard production function (Coelli et al., 2005; p. 331) , i.e. this may be viewed as a special case of the more general specification used by Newman and Matthews. The final simplified equations for the index given in their paper are reproduced for the reader's benefit below. The standard Malmquist can be written

$$\ln M_{oi} = (\ln D_{oi}^{t+1} - \ln D_{oi}^{t}) - \frac{1}{2}\left(\frac{\partial \ln D_{oi}^{t+1}}{\partial t} + \frac{\partial \ln D_{oi}^{t}}{\partial t}\right). \tag{4.5}$$

where the D_{oi} terms are values of a distance function which are equivalent to the inverse of technical efficiency supplied by the model with $TE = \exp(-u)$, or one can simply substitute the inefficiency parameter (u) for each instance $(-\ln D_{oi})$ provided the time superscript is respected. The first term in 4.5 is a representation of TEC, and it amounts to a difference of the inefficiency term over two time periods. The second term is captures movements of the frontier itself, i.e. it is TC, and it is arithmetic mean of the partial derivatives with respect to time. In the particular model specified below, time enters as dummy variables for individual years, so it is the mean of the parameters for any two years' dummy variables that give rise to the TC component. Lastly, a generalisation of the standard Malmquist is required to incorporate scale effects,

$$\ln G_{oi} = \ln M_{oi} \frac{1}{2} \sum_{k=1}^{K} \left\{ \left(-\sum_{k=1}^{K} \frac{\partial \ln D_{oi}^{t+1}}{\partial \ln x_{ki}} - 1 \right) \epsilon_{ki}^{t+1} \right.$$
$$\left. + \left(-\sum_{k=1}^{K} \frac{\partial D_{io}^{t}}{\partial \ln x_{ki}} - 1 \right) \epsilon_{ki}^{t} \right\} \ln \left(\frac{x_{ki}^{t+1}}{x_{ki}^{t}} \right). \tag{4.6}$$

where G_{oi} is the Generalised Malmquist index, M_{oi} is the standard Malmquist index, and the ϵ_{ki} are based on output elasticities with respect to the individual inputs and can be evaluated using

$$\epsilon_{ki}^{t} = \frac{\partial \ln D_{oi}^{t} / \partial \ln x_{\mathrm{ki}}}{\sum_{k=1}^{K} \partial \ln D_{oi}^{t} \, \partial \ln x_{\mathrm{ki}}}. \tag{4.7}$$

Development of the Stochastic Frontier models

There are several variants of the SFA model from which the author must choose the most appropriate for the analysis at hand. In this subsection a brief history of the development of the particular SFA model employed in this work is given, and the justification for the choice of models estimated are presented.

The estimation of stochastic production frontiers using cross-sectional data was simultaneously proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). Assuming a Cobb-Douglas production technology, the stochastic frontier is written as:

$$\ln y_i = \mathrm{B}_0 + \sum_{k=1}^{K} \mathrm{B}_k \ln x_{ki} + e_i \qquad \text{with} \qquad e_i = v_i - u_i \tag{4.8}$$

where y_i is the farm's output level and x_i is a vector of production inputs (capital, labour, etc.). The composite error term e_i consists of a statistical noise component v_i and u_i which is a non-negative technical inefficiency component. The model is usually estimated by maximum likelihood after assuming a distribution for both components. A panel data extension of this model assuming a time-invariant inefficiency term is proposed by Pitt and Lee (1981):

$$\ln y_{it} = \mathrm{B}_0 + \sum_{k=1}^{K} \mathrm{B}_k \ln x_{kit} + v_{it} - u_i \tag{4.9}$$

In effect, the inefficiency of each farm is determined in the first year's observation, and this distribution of inefficiency terms is applied in each subsequent year. Time invariance becomes unrealistic in settings where long panels are used (Alvarez, Arias and Orea, 2006). This panel of data spans 34 years, so models which assume time invariance in efficiency would be unrealistic, even considering that most farms contribute to the survey for a far shorter period.

More recent models allow inefficiency to be a function of time as well as the drivers of inefficiency. Unlike earlier approaches which estimate the determinants of efficiency in an auxiliary regression, Battese and Coelli (1995) followed the single step approach of Kumbhakar, Ghosh and McGuckin (1991) and extended it to panel data, avoiding a source of bias in the process. In their model, technical inefficiency (u_i) is assumed to be a function of a set of explanatory efficiency variables (z_i) and an unknown vector of coefficients (δ_i):

$$u_{it} = z_{it}\delta + w_i \tag{4.10}$$

where w_i is a random variable defined by the truncation of the normal distribution with zero mean and constant variance such that the point of truncation is $-z_{it}\delta$.

Chapter 5 examines distributions of net margin on Irish specialist dairy farms, and in the course of doing so it demonstrates that Irish dairying has considerable variability in terms of outcomes. Such variability can bias estimates of the inefficiency term because farms have different endowments in terms of their natural capital, e.g. soil quality, topography, climate. These effects can be difficult to capture directly, so particular attention was paid to this issue of farm heterogeneity via the use of Greene's (2005) 'true' random effects model. Greene's methodological contribution was to capture some of the consequence of this heterogeneity in newly specified farm effect, thus removing it from the inefficiency estimate.

$$\ln y_{it} = (\alpha + w_i) + \boldsymbol{\beta}' \ln \boldsymbol{x_{it}} + v_{it} - u_{it} \tag{4.11}$$

$$v \sim N[0, \sigma^2]$$

$$u \sim |N[0, \sigma^2]|$$

$w \sim$ with 0 mean and finite variance

This was a panel model, and it was also estimated through Maximum Likelihood, but it was qualitatively different in that it allows for the inefficiency term's time path to vary over individual farms.

The equation above defines Greene's 'true random effects' specification of the stochastic frontier which supplies the parameters for (4.2) above. The model is a special case of a random parameters type of model, where the single parameter which is treated as random is w_i, i.e. part of the component constant term. The model was estimated using the translog functional form, so $\boldsymbol{\beta}' \ln \boldsymbol{x}_{it}$ should be understood to contain all the primary and quadratic terms necessary for the specification.

The choice to model the production relationship, rather than a cost, revenue, or profit function relieves the need to make behavioural assumptions concerning the objective function, i.e. profit maximising, or equivalently cost minimising behaviour. This was particularly useful in the context of Irish agriculture where such assumptions are seemingly contradicted by the data, although this was less of a concern for Irish specialist dairy farm data which less frequently frustrate standard theory. However, this comes at the cost of sacrificing the ability to quantify economic concepts of efficiency; the model can inform the reader about only the technical aspects of production.

Theoretical assumptions

Theory dictates that several conditions be met in order for a production technology to be considered ‘regular’. These conditions manifest themselves as ‘curvature’ of the theorised production (cost) functions, and these are necessary for some of the more orthodox modelling of production (cost) relationships amongst the data.

Firstly, the technology must be ‘monotonic’, i.e. additional inputs to a production function must increase the value of the function. Negative elasticities associated with any of the inputs of a production or cost function imply that additional input reduces output or cost, both of which are antithetical to standard theory. This is separate to the notion of diminishing marginal product, which specifies that additional input must increase production at a decreasing rate, which is a second order condition.

Secondly, the technology must be ‘convex’. Briefly, if there are multiple production plans possible, i.e. different vectors of inputs for obtaining portions of total output, then a convex technology requires altering the shares of output produced by the different production plans will result in—at most—the amount of output obtainable from a single production plan. An analogous argument applies to cost functions, although the inequality is in the opposite direction. A sufficient condition for testing this assumption is the negative semi-definiteness of the Hessian matrix, i.e. the matrix which gives the second derivative of each input in its main diagonal elements, and cross-partials in its off-diagonal elements.

Assumptions regarding the returns to scale are checked via summation of input elasticities. Deviations from unity result in variable returns to scale (VRS) while summation to unity indicates constant returns to scale (CRS).

Econometric assumptions

Stochastic frontier models require that a functional form be specified. A functional form is a mathematical representation of the state of production technology which underpins the model. Choosing the wrong functional form is a source of statistical noise, and this error can affect the resulting estimates of efficiency, so this is seen as a major drawback to the method. Flexible functional forms are commonly specified to reduce this form of error.

Coelli et al. (2005, pg. 211) define flexible functional forms as follows:

> “A functional form is said to be first-order flexible if it has enough parameters to provide a first-order differential approximation to an arbitrary function at a single

> point. A second-order flexible form has enough parameters to provide a second-order approximation."

Coelli et al. go on to list several common functional forms (ibid.). Two of the most common choices are the Cobb-Douglas functional form, and the transcendental logarithmic (translog) functional form. The Cobb-Douglas is first order flexible, and it can be written as

$$y = \mathrm{B}_0 \prod_{n=1}^{N} x_n^{\mathrm{B}_n}, \tag{4.12}$$

whereas the translog is second-order flexible and can be written as

$$y = \exp\left(\beta_0 + \sum_{n=1}^{N} \beta_n \ln x_n + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{N} \beta_{nm} \ln x_n \ln x_m \right). \tag{4.13}$$

The Cobb-Douglas is a simplistic model of production because it is quite rigid, e.g. in its treatment of input substitution elasticities. However, the more flexible translog will have many more parameters by construction, so it can be more difficult to estimate, and its output is also more difficult to interpret.

The composite error term (e_i) of a SFA model contains both a noise component and an inefficiency component. Hence the probability distribution will be a mix of two distributions. The noise component will be a symmetric distribution; it is typically assumed that $v \sim N(\mu, \sigma)$. The inefficiency term is another matter, however.

The rationale of SFA models dictates that the inefficiency term will be asymmetric and strictly positive; but beyond this there is no guidance from economic theory as to which distribution the inefficiency term should actually take. This being the case, most applied work opts for a half-normal distribution, and in the absence of a justification for any specific distribution, this simplifying assumption is taken in this work as well.

4.4 Data

The long term analysis of TFP requires data which dates back to before the implementation of milk quota in Ireland. Farm level data is also needed both because of the microeconometric approach chosen for this analysis, and because there is specific interest in productivity developments at the dairy enterprise level which cannot be obtained from aggregate data.

The panel dataset which meets these criteria was constructed from the NFS (see section 3.2). The unique strengths of this dataset are fully described in Chapter 3, but these can be summarised as relating to; the richness of the data in terms of the number of variables; the quality of the data in terms of sample methodologies; and the duration of the resulting panel.

The sample includes data from 1,844 farms which participated at any point during 1979-2012, yielding a total of 9434 observations. Though the panel spans 34 years, most respondents contribute for a far shorter period than this with average duration at 5.1 years, and the interquartile range of participation being 2 to 7 years.

The variables of interest in this analysis consist of the portion of farm gross output directly attributable to the dairy enterprise as the dependent variable, and five regressors which capture the various types of inputs of this business activity. These were the 12 month average number of dairy cows, direct costs (DC), capital expenditure, labour input in standard man days, and dairy forage area in hectares.

The inclusion of monetized variables was both a concession due to a lack of quantity variables in the cases of certain inputs, and also an allowance for some aggregation of otherwise irreconcilable measures, e.g. a tractor and a farm building. A similar argument could be made for different classes of outputs, e.g. a cull cow and a litre of milk cannot be meaningfully combined except in monetary terms. The need for some variable aggregation stems from the nature of the translog production function used to estimate the model, as it specifies several interactions and squared terms for each input in the primary model. As Newman and Matthews (2006, pg. 196) point out, the aggregation process also alleviates problems concerning the translog functional form's inability to manage zero valued observations of modelled variables.

Direct costs are those which are directly related to the dairy enterprise, and these include concentrate feeds, costs associated with pasture production (mainly fertilisers) and expenditure on lime. Capital expenditure consists of upkeep of land, machinery, and buildings, all of which were not specific to the dairy enterprise, but have been allocated proportionate to the ratio of dairy gross outputs to total farm gross output per farm per year. These measures, being nominal, have all been deflated using appropriate commodity specific price indices obtained from the Central Statistics Office (CSO), hence allowing them to be used as an aggregated volume measure. The same procedure has been carried out for the other monetized variable in the model, i.e. dairy gross output, which was the dependent variable.

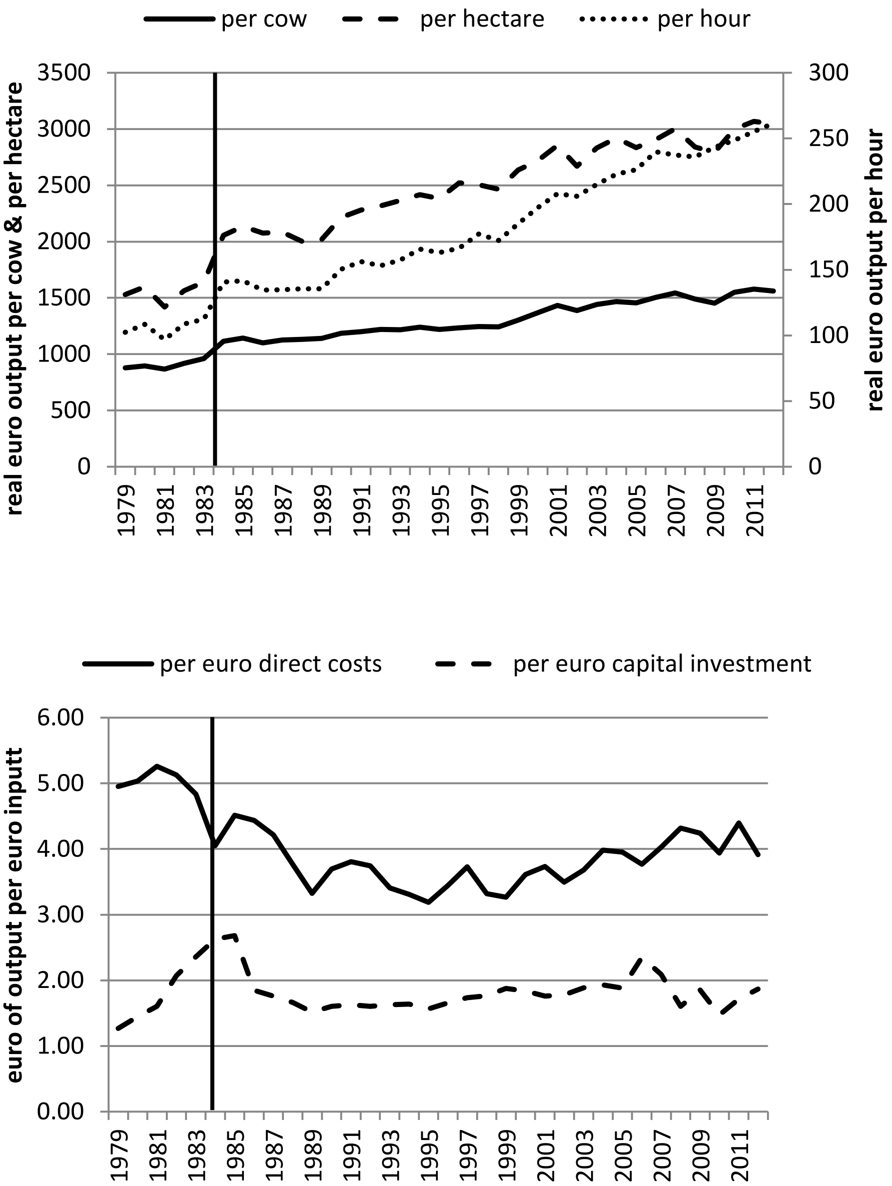
Before moving on to calculating TFP, it is useful to examine a few enterprise-level partial productivity measures. Figure 4.1 portrays the development of several of these.

The top panel displays real euro per cow[6], per hectare of dairy forage area, and per hour of family labour (unallocated). The positive trend in output per cow shows that yield improvements have kept real output per cow growing even after accounting for price movements. The approximately constant distance between output per cow and output per hectare by the later period reflects the essentially static stocking rate by this point; the gap between these two series initially widens in the early years due to a gradually increasing stocking rate. The productivity of labour improves dramatically throughout the period which is likely a sign of the increased specialisation of dairy farms over time, and possibly also the concentration of the sector.

[6] Ireland used the Irish pound prior to adoption of the euro. The exchange rate used for calculating euro values from pounds was 1.27 €/£ in line with standard NFS methodology. Furthermore, the CSO indices which were used to deflate these series used the year 2000 as the base year, and this is the exchange rate which was applicable at the time.

Whilst the choice of particular conversion rate is undoubtedly important for analyses of trade flows, this is less consequential in a single country study. It may effect the levels of the calculated real variables, but their trends and their relationships to one another should be largely unaffected as long as the same rate was used for all of the series.

Figure 4.1 Trends in partial productivity indicators



Source: National Farm Survey (Author's calculations)

The lower panel of Figure 4.1 shows the returns to real euro expenditure on direct costs—mainly purchased feed and fertiliser—as well as the return to on-farm investment which consists of expenditure on livestock, land improvements, and farm buildings. Direct costs and capital investment are partial complements, e.g. larger herds increase demand for feed, and yet the indicators have opposite trends prior to the policy. The productivity of direct costs was already decreasing by the start of the panel, and that trend continues until the mid-1990's. Furthermore, there was an historical over-application of fertilisers on many farms, and this is evident in the falling return to direct costs depicted in the figure. The faster ascent of productivity per hectare relative to productivity per cow reflects a gradually increasing stocking rate which coincided with the sector's consolidation.

Another feature of Figure 4.1 is the pronounced hump in productivity of capital investment. In the run-up to the introduction of a quota policy the productivity of capital was buoyant as the protected milk price stimulated production, but this fell once the quota was in place as there was ample capacity in the system with no outlet for further production.

Table 4.1 Panel summary statistics

	Specialist dairy farms (*n* = 9434)			
	Mean	Standard Deviation	Minimum	Maximum
Size (Ha)	39	24	4	394
Dairy gross output (€, base = 2000)	55,946	48,447	139	747,429
Herd size (dairy cows)	41	27	9	441
Direct costs (€, base = 2000)	15,426	13,824	119	289,719
Capital (€, base = 2000)	46,567	47,561	143	603,024

Source: National Farm Survey

Finally, Figure 3.3 and Table 3.5 from the previous chapter underscore the need to note a few substantial differences in the NFS methodology just at the point of the introduction of milk quota in 1984. The NFS follows a random stratified sample design to ensure the national representativeness of the data within size and production system ‘cells’. Prior to 1984, the sample was expanded or contracted as necessary to ensure its representativeness within the overall farming population, but since 1984 the sample number was essentially fixed prior to collection, and a system of weights was employed to achieve a representative sample. This leads to a situation whereby the sample has a noticeably different distribution across categories of farm size prior to, and after the change in methodology.

Furthermore, the entire panel of farms was resampled in this same year. Thus the panel nature of the data cannot be fully exploited for 1984. This should not adversely affect the TFP index because it was constructed from sample averages (which will still be representative) and because measures will be taken to account for differences in sample design in the model. However, it should be mentioned that the SF model employed is essentially a static model, so dynamic aspects of sectoral productivity development are not explicitly modelled. Identification of any such temporal effects will require a dynamic modelling approach.

The significance of methodological changes in survey design

As noted in section 3.4, the NFS underwent a major methodological change with the introduction of a system of weights in 1984 alongside a complete resampling of the panel of farms. The extent to which these methodological changes matter depends on the sensitivity of the other regressors to the change in frequencies within the size strata. The figures below show the degree of discontinuity in the data for right-hand side variables of the model. It was apparent that the different distributions do have an effect on the regressors. What effect, if any, these discontinuities in the data will have on parameter estimates was unclear, but the “within transformation” cannot be relied upon to rescue the models alone, so it was deemed a necessary precaution to include dummy variables for the classes of the size distribution to control for the possibly obscuring effects of the change in sample design and thereby avoid spurious results. Changes in definitions of farm systems also occurred over time, but this was not the case for the specialist dairy system. Since this analysis was confined to a subset of the farms classified in that system, no extra precautions were needed along this dimension of the data.

The concerns mentioned above pertain to the effect of the change in sampling methods on parameter estimates. However, the validity of generating descriptive statistics from the data was not in question, as the weights used to achieve representativeness in the originally published annual reports were recalculated on the basis of published results, and these were used for any instance of statistical inference.

Figure 4.2 NFS sample distributions of dairy gross output

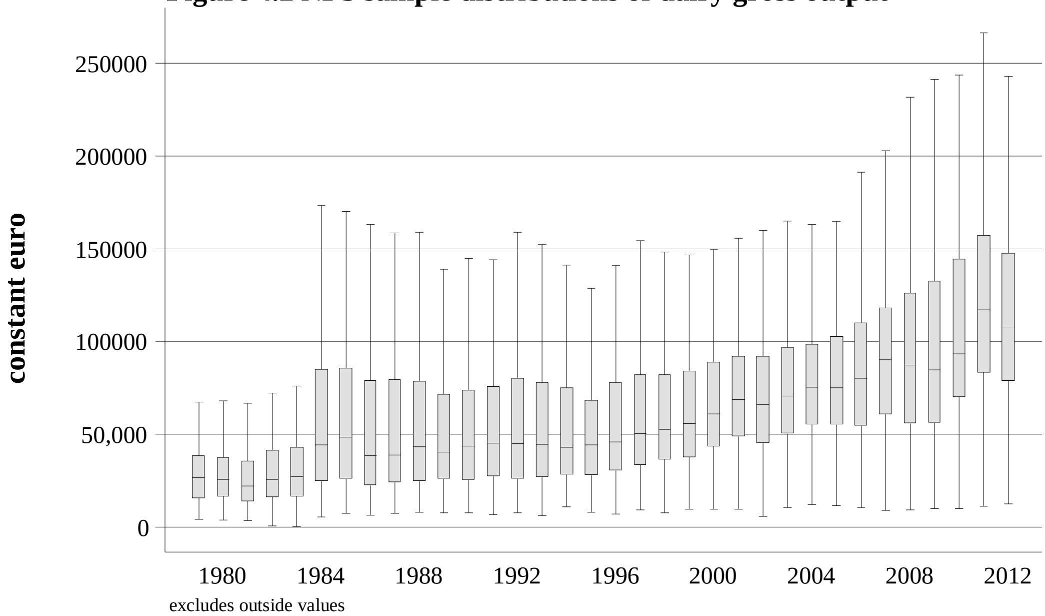
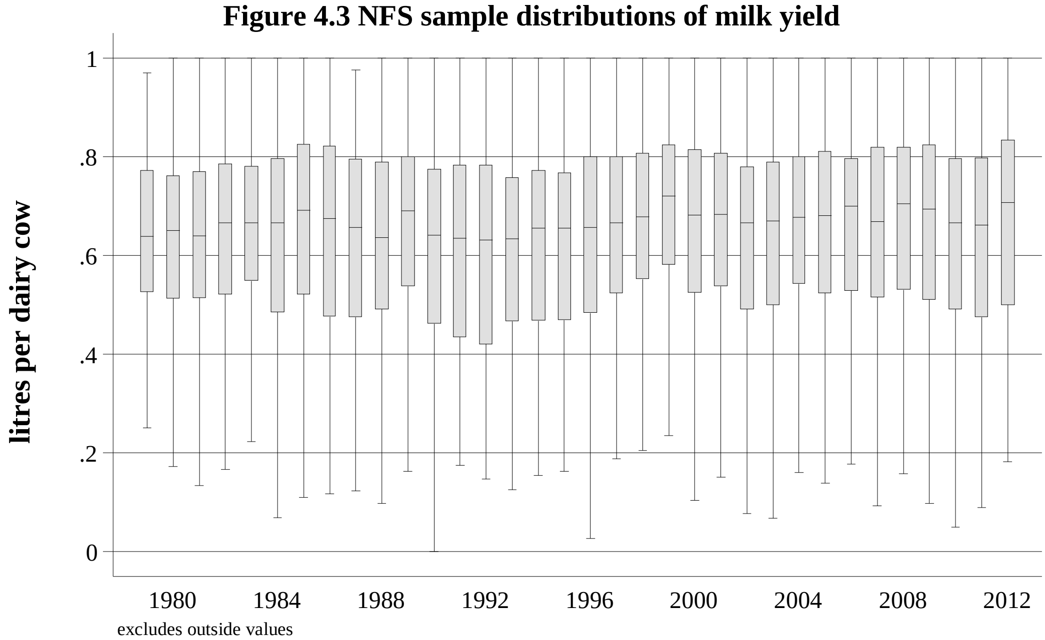
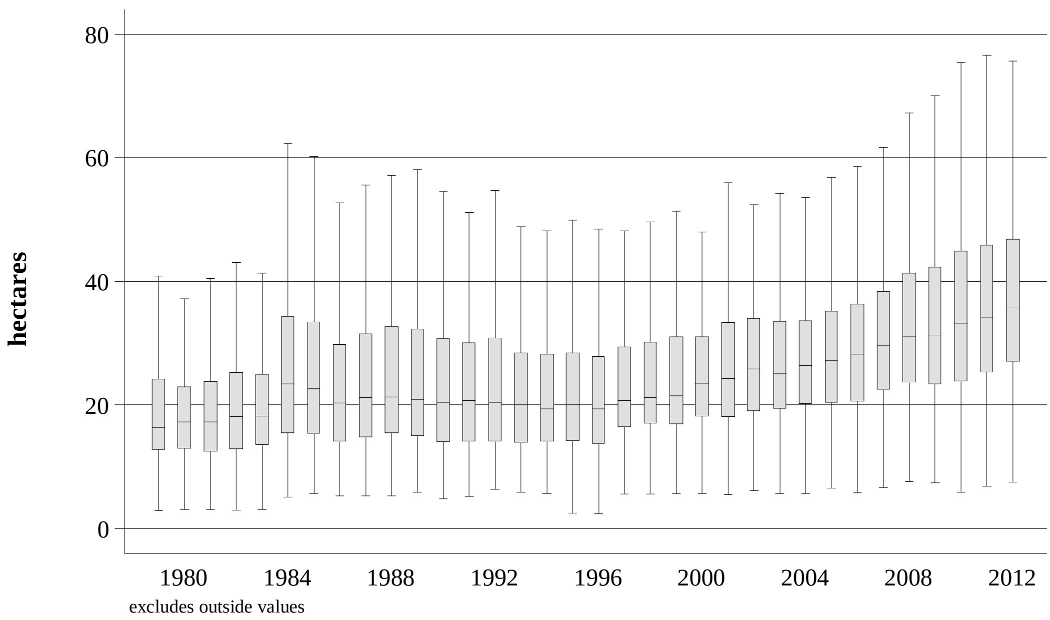


Figure 4.3 NFS sample distributions of milk yield



A separate issue arose in 2012, as the sampling frame was modified to exclude a larger number of smaller farms from the sample than in previous years. The NFS sample is constructed every year in conjunction with the CSO and in accordance with the EC's sampling methodology which aims to include only commercial holdings. This change alters the definition of the minimum size of a commercial holding from €4,000 of Standard Output (SO) to €8,000 of SO. Specialist dairy farms tended to be larger, so the lower bound was effectively irrelevant.

Figure 4.4 NFS sample distributions of dairy forage area per farm



Source: Nationla Farm Survey (author's calculations)

4.5 Results

This section presents the model's parameters and the resulting TFP series. The parameters for the frontier model were reported below in Table 4.2. Herd size and direct costs (mainly feed and fertilisers) were the dominant inputs, and four of the five primary terms were statistically significant at the 99 percent level. All but four of the time dummy variables included in the model were significant at the 99 percent level as well, and these are the basis for the estimates of technical change in the decomposed TFP series.

Four control variables were included to account for the change in the sampling methodology. These variables are indicator variables identifying membership of a farm in one of the size classes which determine the assignment of sample weights for a given farm type and whether the year of the observation is after 1983. Since quota was applicable to all farms, it may be expected that these variables will control for the sampling changes, but will leave global effects of the milk quota policy intact to be captured by the technical change component, i.e. the time dummy variables. These are all statically significant at the 99 per cent confidence level, and their estimates are quite large with respect to the other parameters in the model. This is an indication of the importance of including these controls to avoid bias in the other parameters—most of which remain statistically significant.

The table also reports model parameters specific to the SF methodology chosen. The variance parameters include σ and λ, which are statistically significant from zero. Positive estimates for these support the hypothesis of inefficiency in the data. Furthermore the random effect (α_i) and its variance parameter (σ_{w_i}) are both statistically significant at the 99 per cent confidence level as well.

Table 4.2 Stochastic Frontier model parameters

Log(L)	6,538		
χ^2	13,076		
Sig.	0.00000		
<u>Production function</u>			
Herd (head)	0.70	***	(0.007)
DC (real €)	0.20	***	(0.003)
Capital (real €)	0.05	***	(0.002)
Labour (days)	0.04	***	(0.005)
Forage (ha)	0.03	*	(0.005)
Herd^2	-0.08	***	(0.02)
Herd: DC	-0.10	***	(0.02)
Herd:Captial	0.03	*	(0.009)
Herd:Labour	0.10		(0.02)
Herd:Forage	0.03	***	(0.02)
DC^2	0.03	***	(0.005)
DC:Capital	-0.01	**	(0.005)
DC:Labour	0.01	***	(0.01)
DC:Forage	0.02	***	(0.01)
Capital^2	0.00		(0.002)
Capital:Labour	0.00	***	(0.006)
Capital:Forage	-0.01	***	(0.006)
Labour^2	-0.03	***	(0.006)
Labour:Forage	-0.03	*	(0.02)
Forage^2	-0.01	***	(0.009)
<u>Sampling Method Controls</u>			
Size class 2 control	-0.16	***	(0.012)
Size class 3 control	-0.19	***	(0.013)
Size class 4 control	-0.21	***	(0.013)
Size class 5 control	-0.22	***	(0.015)
λ	1.95	***	(0.052)
σ	0.13	***	(0.001)
σ_u	0.11822		
σ_v	0.06053		
α_i (random effect)	0.07	***	(0.014)
σ_{w_i}	0.03	***	(0.002)

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Technological change (time dummies, base=1979)			
1980	0.02	*	(0.009)
1981	0.02	**	(0.008)
1982	0.07	***	(0.009)
1983	0.09	***	(0.008)
1984	-0.09	***	(0.015)
1985	-0.04	***	(0.014)
1986	-0.06	***	(0.014)
1987	-0.05	***	(0.015)
1988	-0.06	***	(0.015)
1989	-0.08	***	(0.015)
1990	-0.04	***	(0.015)
1991	-0.04	**	(0.016)
1992	-0.03	*	(0.016)
1993	-0.03	**	(0.015)
1994	-0.03	*	(0.015)
1995	-0.03	**	(0.016)
1996	-0.01		(0.015)
1997	0.01		(0.015)
1998	-0.03	*	(0.015)
1999	-0.02		(0.015)
2000	0.02		(0.015)
2001	0.05	***	(0.015)
2002	0.03	**	(0.015)
2003	0.06	***	(0.015)
2004	0.09	***	(0.015)
2005	0.07	***	(0.016)
2006	0.06	***	(0.015)
2007	0.06	***	(0.016)
2008	0.05	***	(0.015)
2009	0.03	*	(0.015)
2010	0.05	***	(0.016)
2011	0.08	***	(0.015)
2012	0.04	**	(0.016)

* , ** , *** = 90, 95, and 99% confidence
Herd = 12 mo. average no. dairy cows,
DC = Direct Costs, i.e. variable costs which are directly attributable to the dairy enterprise on the farm,
Capital = investment in buildings and machinery,
Labour = standard man days,
Forage = farm forage area allocated to dairy herd

Table 4.3 reports actual values of the calculated cumulative indices for the overall and decomposed TFP series alongside (weighted) mean input elasticities and technical efficiency scores. Due to the sampling changes in 1984, the trends ìn the TFP indices are arguably more meaningful then their absolute levels. Therefore, linear growth rates in the indices are also calculated and discussed below.

With respect to the output elasticities, the function was generally increasing in inputs, as theory dictates, but slightly increasing returns to scale were present for most of the panel. The first five years show negative signs on the labour inputs, but after this point all input elasticities were positive. The estimated returns to scale associated with this production function were 1.073 in 1979, but this gradually decreased to roughly constant returns to scale by the final years.

The overall level of TE was generally high, and increasing over time. This was a positive sign for the development of the sector, but it also in part due to the increasing homogeneity of the group of farms classified as specialist dairy producers. The 'true random effects' specification also has the effect increasing TE, as the random effect (meant to capture farm heterogeneity) absorbs some of the variation in output that would otherwise be attributed to inefficiency.

Tables 4.3 and 4.4 reveal that changes in TFP growth were primarily driven by movements in the productive frontier which was represented by the technical change component. This was in agreement with other studies examining both Ireland specifically and for Western Europe generally during this time period (Newman and Matthews, 2006, 2007; Trueblood and Coggins,2003, p. 16).

Table 4.3 TFP index values, Technical efficiency (TE), output elasticities (ϵ), and returns to scale (RTS)

	TFP index values					Output elasticities					
	SC	**TEC**	**TC**	**TFP**	**TE**	**Herd**	**DC**	**Capital**	**Labour**	**Forage**	**RTS**
1979	1.00	1.00	1.00	1.00	0.91	0.86	0.17	0.05	-0.01	0.01	1.07
1980	1.00	1.00	1.02	1.02	0.91	0.85	0.17	0.05	-0.01	0.01	1.07
1981	0.99	1.00	1.01	1.01	0.91	0.88	0.18	0.04	-0.03	0.01	1.08
1982	1.00	1.01	1.06	1.07	0.92	0.84	0.18	0.05	-0.01	0.02	1.07
1983	1.00	1.00	1.08	1.08	0.91	0.83	0.18	0.04	-0.01	0.02	1.06
1984	1.01	1.00	0.92	0.93	0.91	0.78	0.19	0.05	0.01	0.03	1.06
1985	1.01	1.00	0.97	0.98	0.91	0.79	0.18	0.05	0.01	0.03	1.06
1986	1.01	0.99	0.97	0.96	0.90	0.80	0.19	0.05	0.00	0.03	1.07
1987	1.01	0.99	0.97	0.97	0.91	0.79	0.19	0.05	0.00	0.03	1.06
1988	1.01	1.01	0.94	0.96	0.92	0.79	0.20	0.05	0.00	0.03	1.07
1989	1.01	1.01	0.92	0.93	0.91	0.78	0.20	0.04	0.01	0.03	1.06
1990	1.01	1.01	0.96	0.98	0.92	0.77	0.20	0.05	0.01	0.03	1.06
1991	1.02	1.00	0.97	0.99	0.92	0.77	0.19	0.05	0.02	0.03	1.06
1992	1.02	1.00	0.98	1.00	0.92	0.77	0.20	0.05	0.01	0.03	1.06
1993	1.02	1.00	0.97	0.99	0.92	0.75	0.20	0.04	0.02	0.04	1.05
1994	1.02	1.00	0.97	0.99	0.91	0.75	0.21	0.04	0.02	0.04	1.05
1995	1.02	1.01	0.96	0.99	0.92	0.74	0.21	0.04	0.02	0.04	1.05
1996	1.02	1.00	0.99	1.02	0.91	0.74	0.20	0.05	0.02	0.04	1.05
1997	1.02	1.00	1.02	1.05	0.91	0.74	0.19	0.05	0.03	0.04	1.04
1998	1.03	1.00	0.98	1.01	0.91	0.73	0.20	0.04	0.03	0.04	1.04
1999	1.03	1.00	0.99	1.02	0.91	0.72	0.21	0.04	0.03	0.04	1.04
2000	1.03	1.00	1.04	1.07	0.91	0.72	0.20	0.04	0.03	0.04	1.04
2001	1.03	1.01	1.06	1.10	0.92	0.71	0.20	0.04	0.04	0.04	1.03
2002	1.03	1.00	1.04	1.08	0.91	0.70	0.21	0.04	0.04	0.04	1.03
2003	1.03	1.01	1.08	1.12	0.91	0.71	0.20	0.04	0.04	0.04	1.03
2004	1.03	1.00	1.11	1.15	0.91	0.70	0.20	0.05	0.04	0.04	1.03
2005	1.04	1.00	1.09	1.14	0.91	0.70	0.20	0.05	0.04	0.04	1.02
2006	1.04	1.00	1.11	1.15	0.91	0.70	0.21	0.04	0.04	0.03	1.02
2007	1.04	1.00	1.11	1.15	0.91	0.71	0.21	0.04	0.04	0.03	1.02
2008	1.04	0.99	1.10	1.13	0.91	0.71	0.19	0.05	0.05	0.03	1.02
2009	1.04	0.98	1.08	1.10	0.90	0.69	0.19	0.05	0.05	0.04	1.02
2010	1.05	0.99	1.09	1.13	0.91	0.69	0.20	0.05	0.05	0.04	1.02
2011	1.05	0.99	1.13	1.18	0.92	0.67	0.19	0.05	0.06	0.04	1.00
2012	1.06	0.99	1.08	1.13	0.91	0.65	0.20	0.05	0.06	0.04	1.00

Herd = 12 mo. average no. dairy cows,
DC = Direct Costs, i.e. variable costs which are directly attributable to the dairy enterprise on the farm,
Capital = investment in buildings and machinery,
Labour = standard man days,
Forage = farm forage area allocated to dairy herd

Table 4.4 summarises the linear growth rates calculated from the index values in the table above. The overall growth rate was weakly positive, indicative of the fact that the series did not return to the 1979 level until the mid-1990's. The technical change component was the largest component, and it accounted for over half of total growth in the series. Scale change was the next most influential, and it was positive as well. As was apparent from the table above, technical efficiency change was negligible.

Table 4.4 Dairy enterprise productivity linear growth rates 1979–2012

	Generalized Malmquist TFP	Scale change	Technical change	Technical efficiency change
	Period linear growth rates			
	Entire panel			
1979 – 2012	0.20%	0.09%	0.11%	-0.01%
	Pre-quota			
1979 – 1983	1.91%	0.02%	1.87%	0.01%
	Restrictive quota			
1984 – 1989	0.23%	-0.01%	0.18%	0.06%
	Mac Sherry era			
1990 – 1994	0.39%	0.11%	0.32%	-0.04%
1995 – 1999	0.34%	0.10%	0.33%	-0.09%
	Agenda 2000 and quota trade			
2000 – 2008	0.34%	0.08%	0.32%	-0.05%
2008 – 2012	0.54%	0.06%	0.26%	0.22%

A general tendency for stronger and positive growth rates was observed as the panel advances through the various reforms of the CAP and milk quota policy. In the pre-quota period the series is at its strongest growth rate, but this is almost entirely due to technical change. As the series progress through the various eras of the policy, overall growth weakens dramatically, then recovers to mild rates, and scale change become increasingly important.

Surprisingly, the scale change component was never adversely affected at all in the entire period of the sample. This may be a failure of the model to adequately measure the effects of milk quota against a counterfactual scale which would have existed had the policy never been put in place. It may also be the case that some of the effect on scale was actually being capture by movements in the frontier itself, i.e. the technical change component of the model. Another explanation may lie in the fact that the quota limits themselves were based on historical production which was already high.

Technical efficiency change is remarkably static throughout the panel. The largest change is an increase of 0.05 percent in the growth rate for this component of TFP. This occurred in the five years period after milk quota was introduce, but this period also saw an EU wide Milk Outgoers scheme which incentivised permanent cessation of dairy production amongst marginal producers. This may be tentative evidence of a positive effect from that policy. If less efficient farms exited milk production at this time, then that would explain why average technical efficiency improved, both because the remaining farms were objectively more efficient, and because the group of remaining farms would have been more homogenous. However, changes in this component are minimal.

4.6 Conclusions

The results presented in this paper harmonise well with the theory associated with milk quota’s implementation as put forth in Hennessy et al. (2007). Milk quota has been associated with a loss of efficiency, but that this has become less egregious as the policy has allowed for more liberalised trading of quota, thus giving more efficient producers the ability to expand their market share.

In relation to the hypotheses set out in Section 2, this analysis found that the implementation of milk quota was immediately followed by a general decrease in the growth rate of TFP. Furthermore, productivity did improve over time, and inflection points in the series appear to coincide with changes in the policy which theory points to as significant.

Technical efficiency was negatively affected in the early years of milk quota, but improved rapidly around the time of the Milk Outgoers scheme. This was followed by a flat trend, indicative of a certain degree of stagnation. However, it must be said that levels of TE were quite high throughout the sample, so this may just be the effect of being near ‘the ceiling’.

An unexpected result was given by the fact that scale efficiency was at no point in a state of regress. The scale series remained essentially flat until the early 1990’s. The series started showing consistent improvement from then. That time period saw a freeing up of quota trade (albeit with quota still tied to land) and a minor increase in the national allocation of milk quota. A stronger improvement was recorded since the establishment of a quota market mechanism in 2007 although this also coincided with annual increases quota starting in 2009/2010 and continuing until 2013/2014. This will make discerning the relative importance of the market mechanism difficult.

Some of the effects on scale may also be unrelated to policy. Ireland has undergone a period of radical change during the timespan of this panel data, and these doubtless played a part in the progression of these series. An obvious example lies in the fact that Ireland has moved from a more agrarian state to a knowledge-based economy. Exits from farming have progressed at pace, and part-time farming has also increased. These trends exist apart from agricultural policy as the Irish economy has developed.

Furthermore, exogenous movements of the frontier occur as the state of available technology progresses over time, e.g. improvements in herd genetics and better fertility rates associated with artificial insemination. These changes are not directly related to policy measures, although investment in research and development and farm extension services may improve farm-level adoption.

The results suggest that movements of the frontier have been far more influential than the average distance from it. Dairy farms are, and have been, highly technically efficient throughout the sample, when full account was given for the technology that has been available in Ireland.

Chapter 5 The distributional effects of milk quota

5.1 Introduction

Milk quota was applicable across the entire EU, but the policy was implemented at the MS level. This led to differential impacts in practice across regions of the EU. Furthermore, milk production itself remains highly regionalised due to differences in agronomic suitability. These facts can complicate analyses of milk quota policy, but they also give rise to an interesting natural experiment in the case of milk production in Ireland (IE)—where quota has been a binding constraint—and Northern Ireland (NI)—where it hasn't.

Most analyses of milk quotas' effects assert that success in constraining output comes at a cost in terms of efficiency and a slowed rate of structural change; this cost is lessened by allowing for the free trade of quotas. (Oskam and Speijers, 1992; Colman et al, 2002; Hennessy et al., 2009) While many have examined supply response (e.g. Lips and Rieder, 2005; Bouamra Mechemache et al., 2008), structural change (Huettel and Jongeneel 2011; Kirke and Moss, 1987; Ramsden et al., 2005), and efficiency (Hennessy et al., 2009; Colman et al, 2002; Alvarez et al., 2006), comparatively few papers have explicitly analysed welfare or distributional effects of the policy (Henry de Frahan et al., 2011).This study will add directly to this gap in the literature through a comparative analysis of distributions of net margin with and without quota constraints.

The use of a natural experiment provides additional value relative to the usual approaches. The experiment provides a realistic counterfactual and reduces dependence on the usual econometric identification criterion. Furthermore, through comparisons between regions, we are able to use the design of the natural experiment to control for agronomic differences, without the need for individual measurement of the myriad of variables which describe such differences. Changes in agronomic conditions can move entire supply schedules through effects on production functions.

Jongeneel and Tonini (2008) point to the significance of variables that move an entire supply schedule (shifters) in their review of the major partial equilibrium models applied to questions of dairy supply in the EU. In their concluding remarks they say, '[shifters'] importance might easily outweigh other factors and need therefore careful treatment…', and we invoke this argument to justify our attention to this issue.

The comparison of these particular countries also provides a way to address milk quotas' effects on system choice. Despite the geographical proximity of Ireland and Northern Ireland, the development of the dairy sector has proceeded in markedly different ways. Although both countries can be said to be grass-based, Northern Irish dairy enterprises are relatively high-input and high-yield in comparison to farms in Ireland. Differences in quota implementations can partially explain these system differences; For example, Ramsden et al. (2005) find that for those farms where remaining margins after accounting for the price of quota—such as those which prevail in the more productive parts of Ireland—would favour low cost systems, whereas for farms where these remaining margins are higher—as seen in Northern Ireland due to an abundant supply of quota driving down the quota price—favour a high-cost-high-output system.

Ramsden et al. come to these results on the basis of a linear programming model, and they stress that the conclusions are contingent on the assumptions contained therein, e.g.

profit maximisation and technically efficient producers. Guyomard et al. (1996) maintain that tradable quota systems may also make certain classes of producers better off than they would be in an unconstrained market, but they also use a neoclassical approach, hence similar assumptions are necessary. This chapter attempts to test these hypotheses with a minimum of assumptions through the use of non-parametric methods. In this way we aim to give a stronger foundation to the existing literature.

Hypotheses concerning system choice will be of particular interest to any EU member state that, for example, wishes to promote organic farming. Although the adoption of fully organic production in Ireland is quite low, most production systems on Irish farms are already relatively close to organic farming in that they are based on low input intensity. (Läpple, 2010) The focus of Läpple's paper was on the importance of farmer attitudes, but the author also finds evidence of a response to market signals. A natural extension to this finding goes as follows; if smaller margins over quota have been associated with low cost input systems, then the lack of a market for tradable quota may have forestalled the installation of a more input intensive system since non tradable can only be obtained through land leasing or purchases, a far more expensive proposition.

We first present an analysis of averages of cash costs and farm income. Variables are scaled to account for large differences in the average size of operations in each country. We then proceed from this analysis of average levels of inputs to average effects of those inputs via production functions estimated for both countries, and we test the hypothesis that both countries have the same production technology. We then analyse distributions of farm income in both countries and use non-parametric tests under various scenarios designed to account for differences in output prices and in the opportunity costs of land.

The structure of the chapter is as follows. Section 2 presents the microeconomic theory of production as it relates to milk quota. Section 3 relays the relevant historical trends and policy developments. Section 4 describes the methods we applied in the analysis. Section 5 describes the dataset employed in this study. Section 6 presents results of the tests, and the final section draws conclusions from these results.

5.2 Theory and Research Question

Hypotheses of system choice and the distribution of farm income require a microeconomic framework for analysis. Guyomard et al. (1996) sets out such a theoretical framework for understanding production under the milk quota constraint, and their paper provides a method for analysis of both tradable and restrictive quota regimes. This section will supply the necessary theoretical underpinnings using Guyomard et al.'s equations.

The equations which detail the welfare effects for producers operating in a tradable quota regime instead of a restrictive quota regime are set out below. In the current context, and for the reasons set out above, Northern Irish production should be viewed as essentially having no quota constraint at all, i.e. the unrestricted case, whereas the Irish case may be viewed as a restricted regime pre-2007, and as a tradable regime from this period onwards. A short run profit function for the no-quota case would then be

$$\pi\left(p, w, \bar{Z}\right) \equiv \max_{y}\left[\pi = py - C(y, w, \bar{Z})\right] \tag{5.1}$$

Here π is profit, p is output (milk) price, w is a vector of input prices, and $\bar{\boldsymbol{Z}}$ is the cost associated with any fixed factors. In contrast, farmers operating under a quota constraint can achieve only

$$\pi\left(p, \bar{y}, w, \bar{Z}\right) = p\bar{y} - C(\bar{y}, w, \bar{Z}) \tag{5.2}$$

The welfare effects for individual producers are described using a virtual price (shadow price) which is just the price required to induce production at the quota level (i.e. producing 'on quota'). This is just the marginal cost of producing milk at $\overline{y^n}$. Equation (5.3) evaluates the profit maximising condition in a market without quota trade at the shadow price (η) which would induce just the level of production that corresponds to the quota level, given an output price (p) and a quota rental price (r). The superscript n is used here to point out variables which are farm-specific;

$$\begin{aligned}
\pi^n\left(\eta^n, w, \overline{Z^n}\right) &\equiv \max_{y^n}\left[\pi = \eta^n y^n - C(y^n, w, \overline{Z^n})\right] \\
&\equiv \eta^n \overline{y^n} - C^n(\overline{y^n}, w, \overline{Z^n}) \\
&\equiv p\overline{y^n} - C^n\left(\overline{y^n}, w, \overline{Z^n}\right) - (p - \eta^n)\overline{y^n} \\
&\equiv \pi^{r,n}\left(p, \overline{y^n}, w, \overline{Z^n}\right) - r^n\overline{y^n}.
\end{aligned} \tag{5.3}$$

In this theoretical framework a producer cannot be better off in a market without tradable quota than in a no-quota market at a given price level.

$$\pi^n(p) \equiv \max_{y^n}\left[\pi^{r,n}\left(p, \overline{y^n}\right) = p\overline{y^n} - C^n(\overline{y^n})\right] \geq \pi^{r,n}(p, \overline{y^n}) \tag{5.4}$$

In the definition of the profit function for farm n in (5.4) above, the inequality holds because the maximum of $\pi^{r,n}$ is greater than or equal to an arbitrarily chosen value of $\pi^{r,n}$ by definition. Since the setting of quota is not dictated by the vector of prices facing any individual farmer, but rather the judgements of a central authority, and since the quota allocation is not transferrable in this scenario, it is impossible to make that individual farmer better off. If the quota limit is binding for this farmer, then the cost of foregone producer surplus is imposed. If the quota is not binding, the farmer is no better off than in the no-quota case.

However, the same result does not follow for all farms in the tradable quota case. It can be said that a tradable quota regime will make no farm worse off relative to the non-tradable quota scenario. For all farms that continue to produce, and with the superscripts t and r denoting the tradable and restricted quota arrangements

$$\begin{aligned} &\pi^{t,n}\left(p,\overline{y^n},r\right) - \pi^{r,n}\left(p,\overline{y^n}\right) \\ &\qquad = \pi^n(p-r) + r\overline{y^n} - \pi^n(p-r^n) + r^n\overline{y^n}\,) \end{aligned} \tag{5.5}$$

It can be shown that, the convexity of prices in a no-quota market implies that the right-hand side of (5.5) above is non-negative; hence profits in a tradable regime are always at least as good they are in the restricted regime. The intuition here is as follows; a quota market allows producers for whom the quota is binding to expand their production by paying a portion of their producer surplus to farms for which the quota is not binding. It follows that this level of profit is less than the no-quota level for those farms whom obtain extra quota, as shown in (5.6) below

$$\begin{aligned} &\pi^n(p) \geq \pi^n(p-r) + r\,\partial\pi^n(p-r)\,/\,\partial p \\ &= \pi^n(p-r) + r(\overline{y^n} + q^{t,n}) \\ &= \pi^{t,n}\left(p,\overline{y^n},r\right) + rq^{t,n} \\ &\geq \pi^{t,n}\left(p,\overline{y^n},r\right) \end{aligned} \tag{5.6}$$

However, the situation for producers that let out some portion of their quota will depend on the specific prices that prevail in market. To see this, consider the case of a producer moving from a non-tradable quota system to one in which trading is allowed. The gain in profits is the definite integral shown in (5.7)

$$\pi^{t,n}\left(p,\overline{y^n},r\right) - \pi^{r,n}\left(p,\overline{y^n}\right) = \int_{\overline{y^n}}^{y^{t,n}} [p - \eta^n(y^n)]\, dy^n - rq^{t,n} \geq 0 \qquad (5.7a)$$

Whereas the gain in moving to a no-quota scenario is

$$\pi^n(p) - \pi^{r,n}\left(p,\overline{y^n}\right) = \int_{\overline{y^n}}^{y^{u,n}} [p - \eta^n(y^n)]\, dy^n \geq 0 \qquad (5.7b)$$

and finally the benefit of moving from a tradable quota system to a no-quota market is the difference of these two integrals which has been simplified in (5.8) below

$$\pi^n(p) - \pi^{r,n}\left(p,\overline{y^n},r\right) = \int_{y^{t,n}}^{y^{u,n}} [p - \eta^n(y^n)]\, dy^n + rq^{t,n} \geq 0 \qquad (5.8)$$

If $q^{t,n} < 0$, i.e the farm leases out some of its quota, then the effect on profits will depend on the magnitude of the two right-hand side terms. The first is the extra producer surplus attributable to the expansion in output from the tradable quota case relative to the no-quota case. The second is the value of quota trade, which will be negative in the case where when a farm leases out its quota. If the quota traded is more valuable than the extra production, then this farm will be worse off in a no-quota market relative to one with tradable quota rights.

The framework given above leads to a few testable hypotheses. A market mechanism for the transfer of quota was established in 2007 in Ireland. Given the theory stated above, we expect this to have increased not only average net margins, but also to have changed the distribution of farm net margins and shifted the mass rightward relative to the NI distribution (which did not undergo the policy change). Low-cost producers would have been made no worse off under the change, and high cost producers would have been made better off due to the new-found ability to recover additional quota rents.

The reduction of quota rent to negligible levels in "the no-quota" case in Northern Ireland makes for an interesting comparison, but since the data has no observations from before the implementation of quota reforms in NI, the NI data is mainly used as a control group in this setup because the policy that is observable in the data (tradable quota in Ireland) did not directly affect NI.

H_1: The effect of moving from a restrictive quota regime to a tradable quota regime should alter the positions of the distributions before and after 2007 (relative to the control group, i.e. NI); a rightward shift over time is an improvement to net margin, so the SE and BMW distributions should move rightward over time and relative to NI.

The theory above implies that quota rents should be negatively correlated to individual farms' production. The direction of this effect should be the same regardless of the tradability of quota as well. In the tradable quota case, increasing quota rents incentivise farms to forego filling their own quota so that they may lease it out instead. In the non-tradable case, quota values are capitalised into land values because the quota is tethered to the land; again the farm is incentivised to rent out land which implies foregone production.

H_2: If quota values are no longer relevant in Northern Ireland, then a production function should register no effect from this variable, however an Irish production function should register a statistically significant negative effect.

5.3 Policy, agronomy, and structural differences

The dairy sectors in Ireland and in Northern Ireland have been following two different trajectories throughout the time range of our panel. These different development paths may have partially resulted from quota policy, but some of this difference may also have arisen from other sources. This section reviews the distinctions between the two countries in order to better establish the need to accommodate these factors in the experimental design described in the next section.

Northern Ireland is geographically smaller than Ireland, so it is not surprising that there are fewer farms, less output, and a smaller number of dairy cows in the North than in the South. However, Northern Ireland's dairy sector is growing in terms of milk output, increasing by 42 per cent between 1990 and 2010; Ireland's total milk production has remained flat throughout this time (Afbi, 2010; CSO).

Northern Ireland is also intensifying in terms of dairy cows per farm. The total number of dairy cows fell by 23 per cent in Ireland over the same period, but the number of dairy cows remained static during this time in Northern Ireland. At the same time, the total number of specialist dairy holdings has decreased in both countries as the sector consolidates. In Ireland the reduction was by 27 per cent of the 1990 level by 2010; the same statistic is 25 per cent for Northern Ireland (Eurostat).

The quota reform of 1995 gave Northern Irish farms access to a much larger pool of quota from the entirety of Great Britain. This liberalised quota system in the UK facilitated the expansion of production in Northern Ireland, and as a result Northern Irish farms have increased their share of milk production relative to Great Britain. This contrasted starkly with the regionalised quota system implemented in Ireland, whereby large amounts of quota were "ring-fenced" in regions of the country where soil and climate are less suitable for dairy production than e.g. the south-eastern counties (Hennessy et al., 2009). Farms that were capable of higher output could not expand while at times quota went unfilled in other regions of the country.

As stated above, most analyses of milk quota maintain the notion that this supply constraint results in an elevated price level, hence its removal should result in a price reduction. In the case of Northern Ireland—a small open economy—one may expect the local removal of quotas to be inconsequential for output prices because farms are price takers. However, raw milk requires processing, and due to the high transport costs and short shelf life of raw milk, this processing must be accomplished by local processors. Hence the relevant market for raw milk is the local market.

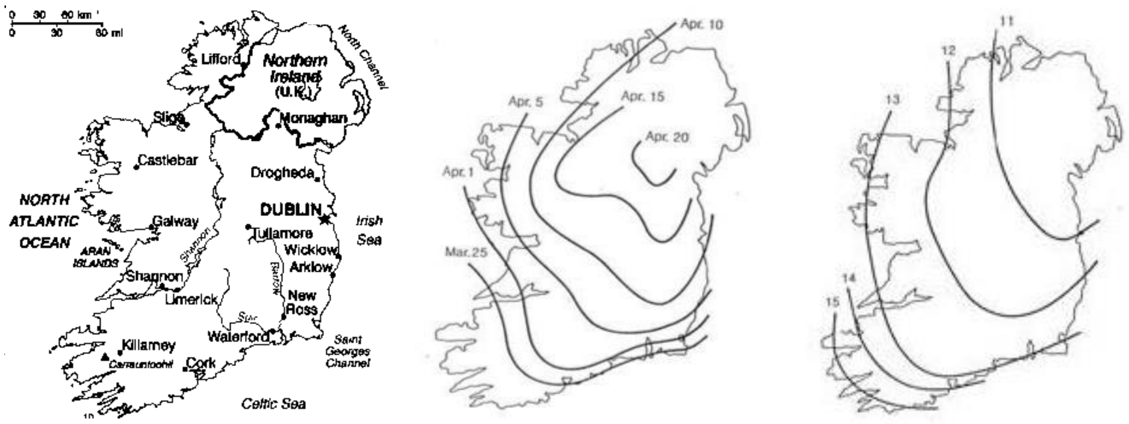
Franks (2002) mentions that the processing sector has undergone significant rationalisation since 2000, and increasing raw milk exports to Ireland from NI suggest a shortage of processing capacity within Northern Ireland. This supports the notion that a short-to-medium-term effect of the removal of quota constraint in Northern Ireland is the reduction of average farm-gate milk prices.

There is another way in which the same reforms that liberalised the trade of quota in the UK may also have contributed to a lower farm gate milk price. Prior to the reforms, entities known as Milk Marketing Boards (MMB) effectively put a floor under milk prices. These have been dissolved from 1995 onwards. Franks (2002) describes the immediate aftermath of the dissolution of the Milk Marketing Boards and the manner in which the role of milk purchaser was taken on by "over 100 licensed organisations" while also demonstrating that "this change resulted in an increase in the variation between producers' milk price" in England and Wales. Most farms initially sold to a large co-operative called Milk Marque, but Franks estimates that this choice incurred a 1.5 pence per litre (ppl) penalty for these farms. Furthermore, volume incentives peeled larger farms and high-premium liquid milk producers away from Milk Marque, as processors attempted to reduce the co-operatives' market power. Since the demise of

Milk Marque, no other milk group has approached the market share that the co-operative controlled, and much of the redistributive effects of the MMB and later Milk Marque's contract structure have been eliminated. If increased variability came mainly at the expense large numbers of small farms, then the average price would likely have fallen.

A logical extension of the narrative that Franks presents would also support the reduction of the farm-gate milk price. With fewer processors, milk processing is both scarcer and more concentrated. With the milk pool more fragmented, and with the retail sector becoming more highly concentrated over time, processors would have both the incentive and the ability to protect their own margins by offering a lower farm-gate price; this would be particularly true for smaller farms that have less market power than larger commercial operations.

Figure 5.1. Spatial distribution of grazing start dates and grass production



(a) (b) (c)

(a) geopolitical boundary,
(b) grass season start dates
(c) estimated grass production (t/ha of dry matter)

Sources: (a)World Fact Book, (b, c) Brereton (1995)

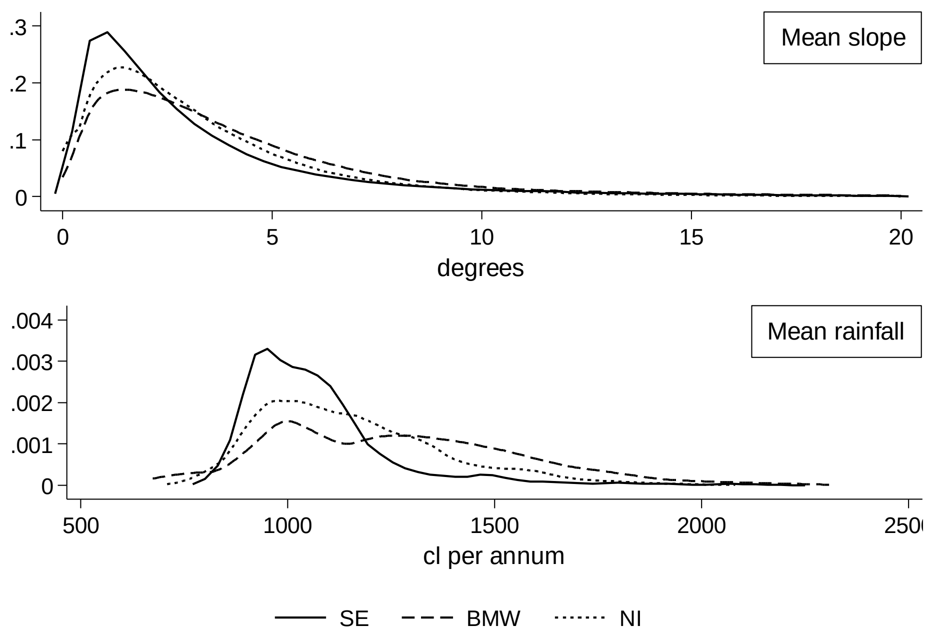
Agronomic differences also loom large over this analysis; the most important of these relates to the use of grazed grass as an input. Although both countries are situated on the same small island, Northern Ireland endures colder minimum temperatures, fewer days of sun, and more frequent frosts. These factors serve to shorten the growing season of grass swards, thus limiting a potential cost cutting strategy for Northern Irish farms, i.e. increasing the ratio of grazed grass in the diet of the herd.

The colder temperatures also increase the number of days for which the herd must be housed, and this also increases costs. It is therefore reasonable to expect that a Northern Irish dairying system would always be more reliant on supplementary feed, ceteris paribus. This is the major justification for the inclusion of the Border, Midlands, West (BMW) sub-region of Ireland in the analysis.

Figure 5.1 and Figure 5.2 both show that the BMW region is more comparable in terms of agronomic conditions than Ireland as a whole. Figure 5.1 illustrates the fact that turn-out dates tend to move from earlier to later in the year as one moves from the southwest to the northeast. It also shows that these turn out dates are correlated with yield potential from grass swards.

Figure 5.2 shows that the distributions of average slopes of farm land and of average rainfall per annum are more closely matched between the BMW region and Northern Ireland than between the south-eastern region (SE) and Northern Ireland. However, whilst the BMW is more similar in terms of agronomic conditions, farm structures here are more different, hence it is necessary to do both sets of comparisons, i.e. the South-East to Northern Ireland and BMW to Northern Ireland.

Figure 5.2. Distributions of agronomic factors



Mean slope of farm land – Top panel, Mean annual rainfall – Bottom panel
Source: Teagasc

The period under study saw a meteoric rise of the Irish economy up until 2008 and from then onwards a tremendous global and national economic collapse. This being case, some macroeconomic effects are bound to complicate the analysis. Agriculture is generally somewhat insulated from larger macroeconomic trends, but there are a few key variables which may be sensitive.

The first consideration we give is to depreciation. This cost item is the largest overhead cost on farms in both samples. In Northern Ireland the trend in this cost has remained essentially flat, whereas it has quickly grown in Ireland. Depreciation cost increased by 75 per cent between 1999 and 2008, but it then fell by more than half between 2008 and 2009.

The FADN definition of depreciation is based on replacement costs, and so it tends to tracks inflation (Commission, 2010: p. 63). Throughout the Celtic Tiger years—but particularly since the year 2000—strong inflation was a feature of the Irish economy (Bermingham et al., 2012: p. 19, Figure 1). Ireland also had a prolonged boom in its construction sector due to a severe housing bubble (Lydon and O’Hanlon, 2012). By 2008, fully 13 percent of the workforce was directly employed by the construction sector (Addison-Smyth et al., 2008). A falling price for the construction of sheds and other farm facilities is plausible given the sector’s collapse, and this is a likely candidate for the fall in depreciation costs in Ireland at that time.

The effects of exchange rates are another concern. The FADN data is expressed in a common currency for all Member States, but this is accomplished through average annual exchange rates. The last two years of the panel witness a dramatic depreciation of the pound sterling (the currency of Northern Ireland) and the euro. In 2007 a single euro traded for 0.698 of a pound, whereas a euro traded for 0.887 of a pound in 2009.

This 27 per cent decline in the value of the pound sterling had the effect of reducing the value of all Northern Irish monetised variable values. However, the effect is purely due to the expression of these variables in euro; it is not visible in the original pound values of costs and revenue variables. This makes monetised variables poor proxies for quantities of inputs when we compare farm structures, and even where reductions in purchasing power are real, they have no connection with the policy variable we wish to test, i.e. milk quota policy. In order to correct for this unusual situation, we've forced the pound to depreciate in line with the linear trend from 1999 to 2007. The resulting exchange rates were applied; in 2008 the adjusted rate was 0.705 GBP/euro, and in 2009 it was 0.712 GBP/euro.

5.4 Methodology

Given that the comparison of Ireland and Northern Ireland can be viewed as a natural experiment in milk quota policy, there is a need to clearly and carefully structure the comparison such that the two countries can be construed as reasonable counterfactuals for the purposes of the experiment. This section justifies and describes the experimental design employed in this analysis.

The classic objection to the use of a non-experimental design in a study such as this is the construction of an adequate counterfactual (Shadish, 2002; p. 18). In an idealised situation, the study would compare effects of some policy or environmental change on a response variable in a carefully constructed experimental setting where all other "confounding" variables have been kept constant. In this way, it is possible to isolate the effect of the variable which is hypothesized to have caused the response as distinct from any other extraneous effects, hence establishing a causal relationship. For large policy changes which effect multitudes of people's livelihoods across wide geographic areas such an experimental design is neither feasible nor ethical.

In the field of economics confounding effects are typically overcome through econometric identification conditions concerning the distribution of error terms in a regression model. In essence, estimating the effects of additional variables which are considered as “controls” allows the research to disentangle the causal relationship between the variables of interest from any confounding effects. Panel methods which transform the data using the repeated observations from a subject can go even further by removing the effects of unobserved variables, i.e. the combined effects of any variables which are missing from the model.

However, large policy changes such as those resulting from the multiple reviews of the CAP—and changes to the milk quota specifically—present a different problem in that these often have to be approximated through a simple binary variable which separates time to before and after periods. This presents a problem in that other changes which occurred at the same time will continue to confound the analysis if there are no other suitable control variables to capture these effects.

In rare circumstances, a better option presents itself in the form of a so-called ‘natural experiment’. In this fortuitous situation, some change has occurred differently in one population relative to another, with an ideal scenario being a true ‘control’ group where the change has not occurred at all. These differences allow for the identification of causal effects as long as the control group provides a believable counterfactual. The policy's effect has been serendipitously captured by the circumstances which led to the experiment in the first place. Meyer (1995) claims that such studies have become increasingly common, and he provides a good survey of economic applications.

We argue that a ‘natural experiment’ exists in the farm data from Ireland and Northern Ireland. For the experiment to exist there must be two populations which are similar to begin with. Geography, climate, culture, and economic development all support the notion that these two countries are very similar. A second requirement for the experiment is that a difference in the ‘treatment’ exists between the two populations. In this context the ‘treatment’ is the quota constraint. Quotas have been tradable in Northern Ireland since the inception of the milk quota in 1984, but quota from the rest of the UK has been accessible to Northern Irish farmers since 1995. The volume of quota available relative to production in Northern Ireland has effectively made quota a non-binding constraint.

The previous section has identified two important classes of differences which may damage the internal validity of the experiment, i.e. agronomic differences and differences in farm structures. Figure 5.3 illustrates the experimental design we employ to account for these factors, along with a table of possible outcomes. Comparisons of the distributions of net margin per hour are drawn between Northern Ireland on the one hand and both of the BMW and the SE regions of Ireland on the other. The figure illustrates the concept that the BMW shares similar agronomic conditions to Northern Ireland, but it is relatively disadvantaged in terms of farms structures (particularly those which relate to scale) relative to the other two regions.

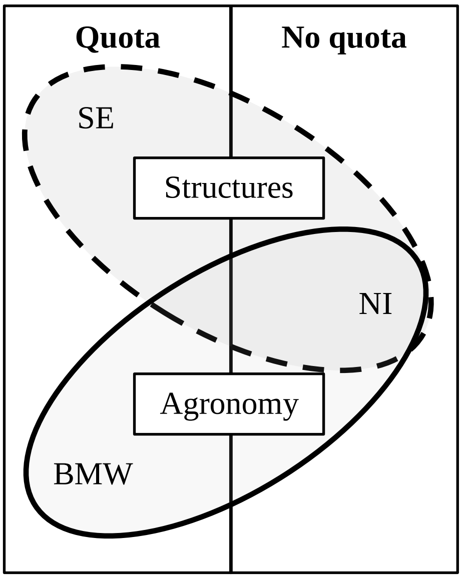
Therefore, hypotheses of the effect of quota must take the results of both comparisons into account to obtain a conclusion which eliminates the confounding effect of these structural and agronomic differences. Suppose that the SE region has three potential benefits relative to the other regions; an agronomic benefit (A), a beneficiary farm structure (S), and an effect which is potentially beneficial—whether direct or indirect—

from operating under a quota system (Q). Suppose also that the BMW region has only a single potential benefit relative to NI in the form of Q, and that NI has only a structural benefit, S.

Under a null hypothesis of no advantageous effect (or a disadvantageous effect) from a quota system we would expect to see the Northern Irish distribution shifted to the right of the BMW region's distribution. If quota has an advantageous effect for BMW farms, then the NI distribution will overlap or be to the left of the BMW distribution. It will simultaneously be located to the left of the IE distribution because this includes farms outside of the BMW region which have better agronomic conditions and a similar structure to Northern Irish farms. These rows of the table have been shaded in light grey. Other possible combinations would indicate negative quota effects, negative structural effects, or both. The rows of the table which are shaded with a darker grey note the outcomes which would contradict the assertion that Northern Ireland and the BMW region are agronomically disadvantaged.

The conclusions from the table do not suppose absolute magnitudes from the potential effects, but only relative magnitudes, i.e. where the strength of one effect can be said to be greater than, less than, or approximately equal to another. These conclusions are based solely on the relative positions of the distributions, and the assumption that the natural experiment adequately accounts for any other confounding variables.

Figure 5.3. Design of the natural experiment and table of logical outcomes



	Location of NI (S) distribution relative to:		Conclusion
	SE (A+S+Q)	BMW (Q)	
1	L	L	$S < Q$
2	L	O	$S = Q$
3	L	R	$S > Q$
4	O	L	$S < Q = -A$
5	O	O	$S = Q = -0.5\ A$
6	O	R	$S > Q = -A$
7	R	L	Contradiction $(A < 0)$
8	R	O	Contradiction $(A < 0)$
9	R	R	$S > Q < -A$

IE = Ireland, BMW = Border, Midlands, West region, NI = Northern Ireland,
A = Agronomic benefit (stictly positive), S = Structural benefit, Q = Quota benefit
L = Left, O = completely overlapping, R = Right

In order to justify this experimental set up we estimate parametric production functions for both Northern Ireland and Ireland. We then test the parameters of these functions to assess the likelihood that agronomic differences are inconsequential. We are also able to test whether the joint value of land and quota have the same effect on production in both countries, which should give further indication of the quota regime's effects.

To this end we employ a test for structural breaks given in Chow (1960). From a statistical point of view, this test asks whether or not additional observations of a single dataset, or more generally, any subsets of the same data can be represented by the same linear model. In essence we ask "does the same regression apply to the farms in both countries?" Using the conventions set forth in Chow's seminal paper, the standard linear model can be written:

$$y = X\beta + \epsilon, \tag{5.9}$$

then dividing our sample into groups we have

$$y_1 = X_1\beta_1 + \epsilon_1, \tag{5.10}$$

$$y_2 = X_2\beta_2 + \epsilon_2. \tag{5.11}$$

A reasonable assumption in most economic contexts is that only a subset of the parameter coefficients will be the same across subsets of the data. Splitting the explanatory variables in $\boldsymbol{X_1}$ into subsets $\boldsymbol{Z_1}$ and $\boldsymbol{W_1}$, doing the same for $\boldsymbol{X_2}$, and ascribing to each the parameter vectors γ and δ respectively we have,

$$y_1 = X_1\beta_1 + \epsilon_1 = Z_1\gamma_1 + W_1\delta_1 + \epsilon_1, \tag{5.12}$$

$$y_2 = X_2\beta_2 + \epsilon_2, = Z_2\gamma_2 + W_2\delta_2 + \epsilon_2 \tag{5.13}$$

at which point we can test if estimates of those parameters which we expect to be the same are within a confidence interval. If γ represents the set of parameters that we are interested in testing across either the groups or time periods delineated by the subscripts above, then hypotheses for the test are

$$H_0 : \gamma_1 = \gamma_2 = \gamma \tag{5.14}$$

$$H_a : \gamma_1 \neq \gamma_2 \neq \gamma \tag{5.15}$$

The test is carried out by applying the following F statistic,

$$F(q, m+n-2p) = \frac{Q_3/q}{Q_2/(m+n-2p)} \tag{5.16}$$

where—if $\boldsymbol{Q_1}$ is the quadratic form of the residual sum of squares under the null hypothesis then—$\boldsymbol{Q_2}$ is the quadratic form under the alternative hypothesis and $\boldsymbol{Q_3}^*$ is the quadratic form of the differences[7]. Furthermore, n is the number of original observations, m is the number of additional observations, p is the number of parameters (i.e. the number of explanatory variables in the model less one intercept, or the sum of the lengths of vectors γ and δ), and q is the number of parameters over which the test is carried out (i.e. the length of the vector γ).

There is a precedent for the comparison of kernel densities under various scenarios to analyse effects on distributions of wages (DiNardo et al., 1996). Our analysis does the same for net margin per hour, i.e. the 'wage' the farmer is effectively paid for an hour of labour input. The scenarios make three assumptions: firstly that the same farm gate milk price applies in Northern Ireland and in Ireland, secondly that the opportunity cost of owned land is a realised cost, and finally that both of these conditions apply simultaneously. Unlike DiNardo et al., we apply the non-parametric Kolmogorov-Smirnov (K-S) test of equality of distributions.

The K-S test compares two empirical distribution functions $F_{1,n}$ and $F_{2,n'}$ looking to see if they originate from the same arbitrary distribution. The generated test statistic is

$$D_{n,n'} = max\,|F_{1,n}(x) - F_{2,n'}(x)| \tag{5.17}$$

with the rejection criterion

[7] See Chow (1960: 597) for a rigorous discussion of these quantities and a proof of the test under varying assumptions.

$$D_{n,n'} > c(\alpha)\sqrt{\frac{n+n'}{nn'}} \tag{5.18}$$

where n and n' are the sample sizes of the respective empirical distibutions. Rejection of the null hypothesis implies that the samples come from different underlying distributions.

The K-S test is easy to compute, and it has comparable statistical power to other non-parametric and parametric tests. Being a non-parametric test, it does much better than parametric alternatives when the assumption of normality is violated (Meyer and Rasche, 1989; p. 8). Another key strength—and the main reason this analysis employs the K-S test—lies in the fact that it is also sensitive to the shape of the empirical distributions under study; many other tests consider only the location and scale of the empirical distributions (ibid.; p. 9).

We carry out the K-S tests for distributions generated by each year of the sample in each country, as well as selecting the BMW region from Ireland. These comparisons allow us to test for the existence and direction of the effect of milk quotas while assessing the impact which agronomic conditions and farm structures will have had on the comparisons.

The approach taken does not allow for estimates of the magnitudes of milk quota's effect. However, we also test net margin per hour with the scenario modifications applied in an effort to determine if output prices and the opportunity costs of land drive differences in the distribution of net margins. These particular scenarios are justified by the theoretical framework set forth in section 5.2 and the policy history given in section

5.3. Output prices are expected to be lower in the no-quota case and the opportunity costs of land should also reflect capitalised quota values.

5.5 Data

This section justifies and describes the use of the FADN dataset for this analysis. Aggregate data suffers from a greater degree of aggregation bias; some hypotheses cannot be tested without strong assumptions; and there is little scope for accommodating heterogeneity in the underlying populations. (Colman, 2005; pg. 240) It is important for this study to avoid all of these weaknesses, but particularly so in the case of heterogeneity across farms, as special attention is being given to the effects of the policy on the distribution of net margin.

In order to conduct an effective micro-analysis, the data must provide consistent variable definitions in order to avoid spurious comparisons, it must contain detailed information, panel data is highly desirable to control for farm effects, and it should embody high collection and data management standards to minimise measurement error. Section 3.3 established that the FADN data has all of these traits, and so it is the primary source of data used in this analysis.

There are challenges in using the FADN data, however. The FADN is only designed to be representative of ‘commercial’ farms. In practice, only farms that are above an economic size threshold will be represented, so any effects on the smallest farms in either population—which may skew towards benefits from the trade quota—will be absent.[8] The dataset is not designed to calculate aggregate statistics. Consequently, where aggregate measures were necessary these were sourced from more appropriate databases, e.g. the Farm Structures Survey. Lastly, the FADN data available for this study went as far back as 1999 only, therefore a complete picture of the history of milk quota implementation was not possible. Nor indeed was it possible to assess the reforms in milk quota which took place in 1995 in Northern Ireland. The major change which can be observed is the implementation of a market for tradable quota in Ireland.

The period of study ran from 1999 to 2009, yielding an unbalanced panel of 3,132 observations of 1,142 farms. Farms stayed in the panel for an average of 2.7 years, but this differed across countries; mean duration was 2.6 years in the Irish sample and exactly three years in the Northern Irish sample.

We confine the analyses to the specialist milk producers as defined by the FADN. These farms derive 2/3 of their standard gross output (SGO) from cow's milk and milk products. However, there are other enterprises present on the vast majority of even these specialised farms.[9]

The FADN data provides expenditure measures for various cost categories at the whole farm level, i.e. inclusive of other non-dairy activities on the farm. To conduct the analysis at the enterprise level it is necessary to allocate only a portion of these costs to the dairy enterprise. We follow the methodology set out in the Commission's (2010)

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[8] The threshold for the FADN's sampling frame is specific to each region and may change over time. The threshold for Ireland was a constant two economic size units (ESU) throughout the panel, but the Northern Irish threshold was 4 ESU in 1999, and it rose to 8 ESU for the remaining period. The sample selection for dairy specialists would have rendered these differences inconsequential for this work.

[9] We note that this sample will differ from that constructed in the Commission's 'Dairy farms report 2010' (EU Commission, 2010) which includes less specialised dairy farms.

'Dairy farms report 2010' to allocate costs. In broad terms, direct costs (specific costs in FADN terminology) are allocated on the basis of LU ratios, whereas the remaining costs are allocated on the basis of gross output ratios.[10]

Typically, economic analyses should be based on economic concepts of cost. These differ from financial or accounting costs in that they are more expansive; economic costs consider opportunity costs which are the cost of the best alternative use of any given input. The scenarios presented in section 5.6 will address these opportunity costs incrementally by first imputing an economic cost for land (based on rental values) because quota values are assumed to be at least partially capitalised into land values. The remaining unpaid factors are added to the opportunity cost of land as a next step, e.g. family labour and unpaid capital costs. We have again followed the methodology set out in the E.U. Dairy Report in calculating these costs. Colman et al. (2002) found that the imputed cost of family labour was a much larger proportion of total cost for smaller farms in their sample. That finding is likely to be born out here as well. We echo the authors' caution; "[…] if such producers value their labour at a lower rate […] then the economies of size available are reduced." To this we add a concern regarding the segmentation of labour quality, and for the relative tightness of local labour markets. Unfortunately, it is beyond the scope of this analysis to make special provision for these potential differences.

As we employ a log-linear model specification for the Chow test, it was necessary to address missing and zero valued observations of our variables. In practice this only affected two variables; these were fertiliser expenditure (20 observations) and paid

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[10] Data limitations cause some minor differences in the methodology. Details are available upon request.

labour. The observations which recorded zero values for fertiliser expenditure were dropped from our analysis since the number of affected observations was proportionately small. The variable measuring paid labour was given special treatment as many farms—particularly in the South—recorded no paid labour at all. The value of paid labour was changed from zero to one hour per annum on these farms to facilitate the log transformation and to avoid losing a third of the Irish sample. This change affected 1,389 observations on 584 farms overall, and 1,320 of these observations were on farms in the South.

5.6 Results

This section reports the results of the analyses conducted in this chapter. First, the analysis of farm structures is presented, and this is followed by the study of quota's impact on distributions of farm income.

Farm Structure

The FADN data contains several variables which may be used to compare farm structures and production systems across countries. In this section we calculate average levels of these variables and conduct hypothesis tests to guard against the possibility that differences in these means across countries could result from sampling variation alone. If Ramsden et al.'s (2005) hypothesis that higher margins over quota incentivises high-input, high-output production systems holds true then t-tests of input and output related variables should confirm higher levels in Northern Ireland as very low quota prices should result in higher margins over quota.

Comparisons and tests of farm structures are given in Table 5.1. Farm size, forage area, and the herd size variables all report substantially higher mean values for Northern Irish farms than for Irish farms. The only variables in the table reporting similar mean values for both countries are the labour intensity variable and the stocking rate. Indeed, the values are virtually identical. It is worth noting, however, that this measure excludes contract labour which is a major input on Northern Irish farms. Two of the unit-scaled variables also report system differences; Northern Irish farms are more heavily stocked, and herds in the north are higher yielding on average.

Figure 5.4 shows differences in the mean levels of output, costs, subsidies, and family farm income.[11] The vertical axis ranges from -800 €/ha to 600 €/ha, and it marks amount by which the Irish level exceed the Northern Irish for output, costs, subsidies, and family farm income (FFI, which is equivalent to net margin plus any subsidies).

Table 5.1 Mean values of structural variables (1999-2009 average)

			Two-sample t-tests	
	Ireland	Northern Ireland	t-stat	p-value
Dairy cows (LU)	49	71	-12.9	0.00
Other cattle (LU)	37	45	- 4.8	0.00
Farm size (ha)	46	60	-10.7	0.00
Dairy forage area (ha)	26	36	-13.8	0.00
Stocking rate (LU/ha)	1.88	1.94	- 1.5	0.15
Labour intensity (hours/dairy cow)	58	53	- 0.1	0.89
Milk yield (litres/dairy cow)	4981	5907	-23.2	0.00
Age of holder	49	56	-18.3	0.00

Source: FADN data (averaged over all years)

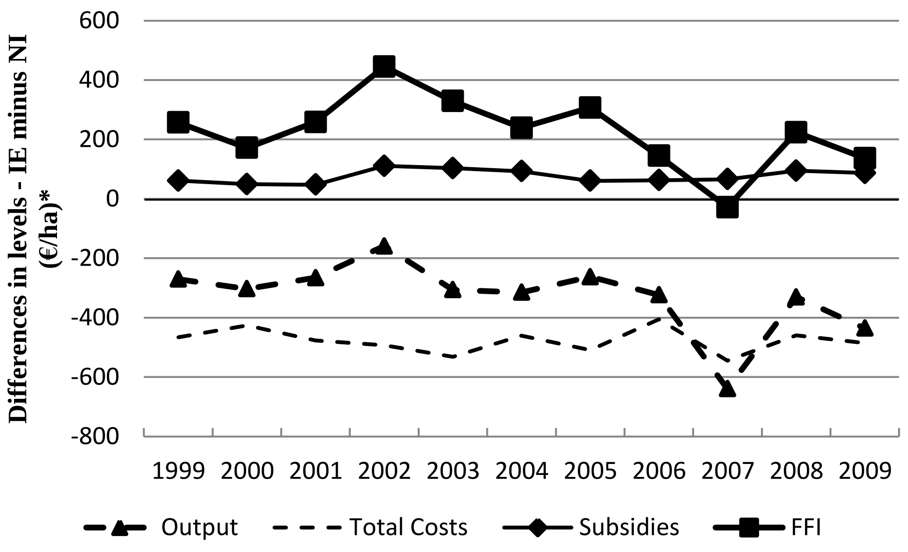
Negative values indicate variables for which the Northern Irish level exceeds the Irish level. Both output and costs tend to be higher in Northern Ireland in most years, and this

[11] The reader is reminded that calculations proceed on the basis of the adjusted exchange rates discussed in the final paragraph of section 5.3.

is represented by the distance below the horizontal line at zero in the figure. With the exception of 2007, Northern Ireland's output advantage is wiped away in all years by costs which exceed the level in the South by an even larger amount. Hence, net margin per hectare in Ireland exceeds that observed in Northern Ireland in most years.

The average family farm income per hectare is higher in Ireland than it is in Northern Ireland in most years of the panel. There is also a higher mean level of subsidies per hectare, but most of Ireland's advantage in family farm income results from its higher net margin per hectare.

Figure 5.4. Differences in whole farm financial indicators



Source: FADN data
** Using adjusted exchange rate in GBP/€, 2008 = 0.705, 2009 = 0.712*

Further evidence of Northern Ireland's preference for a high-input system is given in Table 5.2; it decomposes direct costs into its constituent parts on a per hectare basis. Feed in Northern Ireland averaged nearly double the value per hectare observed for

Ireland over the final three years of the panel. Other livestock costs include veterinary costs and fees for artificial insemination, and these were 17 per cent higher in Northern Ireland than in Ireland. Other costs include pesticides, reseeding, and other crop associated costs; this cost category is very small and at similar levels in both countries. The difference in fertiliser expense was statistically significant in the two-sample t-test, but the mean levels are virtually identical, indicating that while Ireland has a larger average per hectare fertiliser expense, this difference is not large.

Table 5.2 Dairy enterprise direct cost components (€/ha)*

			Two-sample t-tests	
	Ireland	Northern Ireland	*t*	p-value
Feed costs	641	1180	-17.7	0.00
Fertiliser costs	177	176	2.8	0.01
Other livestock costs	209	246	-10.7	0.00
Other costs	16	18	-1.5	0.13

Source: FADN data (averaged over 2007, 2008, and 2009)
** Using adjusted exchange rate in GBP/€, 2008 = 0.705, 2009 = 0.712*

Table 5.3 examines the remaining cost categories, all of which fall under our definition of overhead costs (i.e. those costs which are not directly related to a particular enterprise). Barring interest and wages, every cost item is larger in Northern Ireland than it is in Ireland on a per hectare basis. The largest differences are in depreciation and energy. Some of the differences in the mean levels reflect the increased specialisation and intensity of Northern Irish farms relative to Irish farms, as unit prices for items such as energy and rent are smaller in the North than in the South.

Depreciation is the largest cost item, but beyond the difference in the mean levels shown, this item follows vastly different trends in the two countries. We posit that these different trends largely reflect a boom and bust cycle in Irish housing and generally high inflation exhibited in the latter years of the Celtic Tiger, as described in section 5.3

Table 5.3 Overhead cost components (€/ha)*

	Ireland	Northern Ireland	Two-sample t-tests	
			t	p-value
Depreciation	345	438	-22	0.000
Machinery & buildings current costs	163	182	-1.9	0.061
Contract work & machinery hire	121	138	3.1	0.002
Energy	99	170	-34.6	0.000
Interest	67	66	-5.7	0.000
Wages	72	57	3.6	0.000
Rent	68	95	-7.8	0.000
Other costs	65	140	-52.8	0.000

Source: FADN data (averaged over 2007, 2008, and 2009)
** Using adjusted exchange rate in GBP/€, 2008 = 0.705, 2009 = 0.712*

Table 5.4 gives the results of the two estimated models, the Chow tests, and the tests of joint significance. As the production functions were estimated using the Cobb-Douglas functional form, the resulting estimations are carried out as log-linear models. Hence, the coefficients can be interpreted as elasticities, i.e. the percentage change in output attributable to a one per cent change in a given variable.

We observe similar magnitudes for the coefficients of some variables, but it becomes apparent that there are large differences in the parameter estimates for nearly half of the regressors. Farm size, paid labour, unpaid labour, and feed all show relatively large changes in their estimates. However, this straightforward comparison does not establish the difference of these effects. Sampling variation will dictate that the parameter estimates of two different samples will almost always differ. This provides the motivation for the Chow tests.

Table 5.4 Model of milk output† (litres milk equivalent) and Chow test results

Y = Milk †	Units	Ireland Coef.	Ireland p-value	N. Ireland Coef.	N. Ireland p-value	Chow tests p-value
Land & quota †	€/ha	-0.03 (0.01)	0.01	0.03 (0.02)	0.14	0.01
Fertiliser †	€/ha	0.02 (0.01)	0.10	0.10 (0.02)	0.00	0.00
Forage area †	€/LU	-0.57 (0.03)	0.00	-0.51 (0.04)	0.00	0.19
Feed †	€/LU	0.12 (0.01)	0.00	0.21 (0.02)	0.00	0.00
Paid labour †	€/LU	-0.01 (0.00)	0.01	-0.03 (0.01)	0.00	0.01
Unpaid labour †	€/LU	-0.20 (0.01)	0.00	-0.50 (0.03)	0.00	0.00
Age	Years	0.00 (0.00)	0.84	0.00 (0.00)	0.01	0.01
Farm size †	Ha	0.71 (0.02)	0.00	0.77 (0.03)	0.00	0.09
Environmental schemes	(D)	-0.01 (0.01)	0.41	0.04 (0.02)	0.04	0.02
Minimum temperature †	°C	-0.23 (0.33)	0.48	1.04 (0.44)	0.02	0.01
Altitude zone	(D)	0.01 (0.05)	0.81	-0.11 (0.05)	0.02	0.10
Intercept		10.26 (0.57)	0.00	8.35 (0.74)	0.00	0.03

	Stat	p-value
Joint Chow test	340.81	0.00

Source: Authors' calculations
Notes: D – dummy variable, † – logged variable, (s.e.)

The rationale behind the tests is simple; if the two samples are actually providing differing estimates for the same underlying function, then the difference between the parameter estimates for any given variable should not be significantly different from zero. The Chow test can be implemented for entire equations, or for any subset of regressors which we believe may be different. The tests were carried out for the overall equations and for each individual variable, the results of which are presented in Table 5.4.

Two variables are of particular interest; first among these is the value of land and quota. This variable is statistically significant with a negative sign in the Irish model, but the sign changes to positive in the Northern Irish model where its effect cannot be statistically established at all. In Ireland, the variable's sign and statistical significance are in agreement with the reasoning put forth in section 5.2, i.e. quota values are negatively correlated with production due to the incentive to lease out quota directly, or land with attached quota when direct quota trade is not possible. In NI, the variable may more closely reflect land quality which should have a positive correlation with output.

The second variable to be highlighted is average annual minimum temperatures. This data is not farm specific; it is constant within each country in any given year. It is not statistically significant in Ireland, but it is the most consequential variable in the Northern Irish model where higher minimum temperatures increase production. This is strong evidence for the agronomic differences discussed in previous sections.

Eight of the 11 exogenous variables yield a Chow test statistic which rejects the null hypothesis at the 95 percent confidence level. Another variable rejects at the 90 percent confidence level, and a joint Chow test rejects the null hypothesis at the 99 percent level. The conclusion is that both agronomic and structural differences must be controlled for in the design of the experiment, hence separate comparisons to Northern Ireland will be carried out for the SE and BMW regions in the following section.

Comparisons between Ireland as a whole with Northern Ireland also provide mixed evidence of the hypothesis that larger margins above quota induce high-cost, high-yield systems of production. Individual years' comparisons support the hypothesis, but the trend in pre and post quota market reforms in Ireland show no evidence of a convergence in system type as might be expected.

Farm Distributions

The analysis of net margin distributions proceeds below. The tests were conducted under six scenarios, all of which use the correction for the depreciation of the pound sterling discussed earlier. The baseline applies no other adjustments. Scenario 2 controls for differences in the average farm-gate price level in the two countries. Scenario 3 accounts for the opportunity cost of land, but omits the price equalisation. Both the price equalisation and the land adjustment are applied in scenario 4, with the remaining economic costs applied in scenario 5. Scenario 6 accounts for quota income.

The layout of the results is repeated for each scenario's table. The table contains p-values for both K-S and t-tests, with each test being carried out between NI and either the SE or the BMW region. Counts of the number of tests which reject the null hypothesis of equivalent distributions are tabulated in the final row of each column. The tests themselves provide some indication of confidence that differences between the samples cannot be due to sampling variation alone; information on the relative location and shape of the distributions are provided by the kernel density plots which are displayed alongside the p-values. The plots are from the year before and the year after the introduction of a market for quota in Ireland in 2007; their p-values are also shaded grey. These particular years are also more typical than either 2007 (a bumper year) or 2009, which saw a collapse in milk prices.

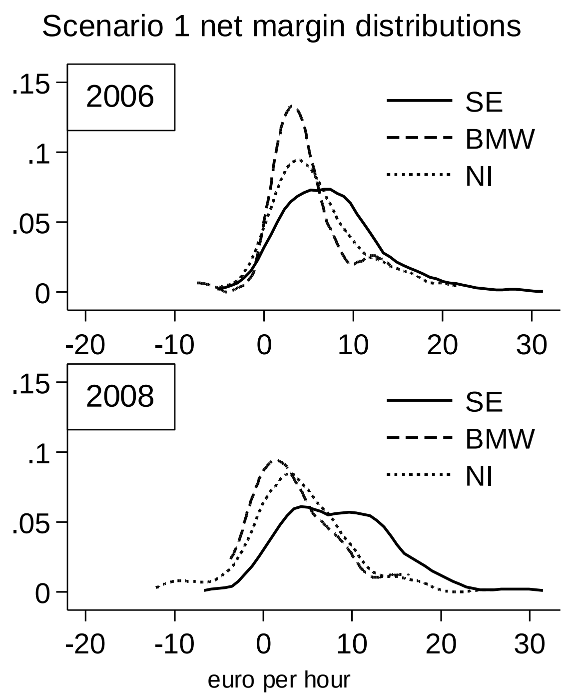
The results exhibit a few patterns which are common to all of the scenarios. The p-values for both the K-S tests and the t-tests indicate a statistically significant difference in the IE and NI distributions of net margin in most years, whereas the null hypothesis most often cannot be rejected for the BMW-NI comparison. The tables also reveal K-S test's additional sensitivity to distributions' shapes as compared to the t-test; the K-S is more often statistically significant. Even the K-S test has limitations; many plots show clear differences between the shape of the NI and BMW distributions, but the differences tend to cancel out over the entirety of each, thus leading to a failure to reject the null hypothesis, and justifying the accompanying graphical analysis.

A recurring feature in many of the plots is that the BMW distribution is more 'peaked' than the other distributions. This peak is shifted slightly left of the other distributions, and the area in the right tail of the distribution is smaller. This means that more farms in the BMW have relatively poorer outcomes relative to the other two analysis regions. A chief interest of this analysis is what happens when moving from the 2006 plot to the 2008 plot in each scenario, and these changes will be reported below.

Table 5.5 presents the results of the first scenario below. The plots show that the NI distribution is less peaked than the BMW distribution in 2006, and this peak is slightly to the right. Furthermore, a dip in the right tail of the BMW distribution does not appear in NI. However, the tests fail to reject the null hypothesis in 2006, so differences in the distributions may appear due to sampling. The comparison with the South-East shows a broader distribution of outcomes, and the distribution is shifted rightward of the other two, thus indicating the effects of agronomic and structural advantages in this region. This arrangement appears as the third row in Figure 5.3, and it supports the notion of a benefit from the quota system which is smaller than the structural benefits.

Table 5.5 Tests of distributions of net margin per hour—Scenario 1– baseline

Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.766	0.001	0.198
2000	0.015	0.202	0.007	0.203
2001	0.000	0.610	0.000	0.904
2002	0.000	0.297	0.000	0.474
2003	0.000	0.013	0.000	0.557
2004	0.000	0.273	0.000	0.081
2005	0.039	0.169	0.057	0.107
2006	0.007	0.266	0.002	0.804
2007	0.205	0.037	0.179	0.932
2008	0.000	0.375	0.000	0.516
2009	0.000	0.204	0.318	0.415
Count p<0.05	10	2	8	0



Source: Author's calculations

The distributions are noticeably changed in the wake of the establishment of a market for quota. The 2008 plot shows a much reduced peak in the BMW distribution, and the dip in the right tail has disappeared. All three distributions have broadened out, and most farms see an improvement in net margin, as illustrated in the plot by the "stretching" of the distributions towards the right. However, the NI distribution changes relatively little, which supports the notion that these changes are in fact due to the new quota regime. The SE, in turn, sees more benefit than either the BMW or NI regions; it has become very nearly bi-modal. This corresponds to the second row of Figure 5.3 which shows a benefit from quota in the BMW which effectively balances the structural benefit in NI. This benefit is also visible in the movement of the SE distribution. However, the lack of statistical significance in the SE-NI comparison in both years supports the result, but lack of a rejection in the BMW-NI comparison in 2006 weakens it somewhat.

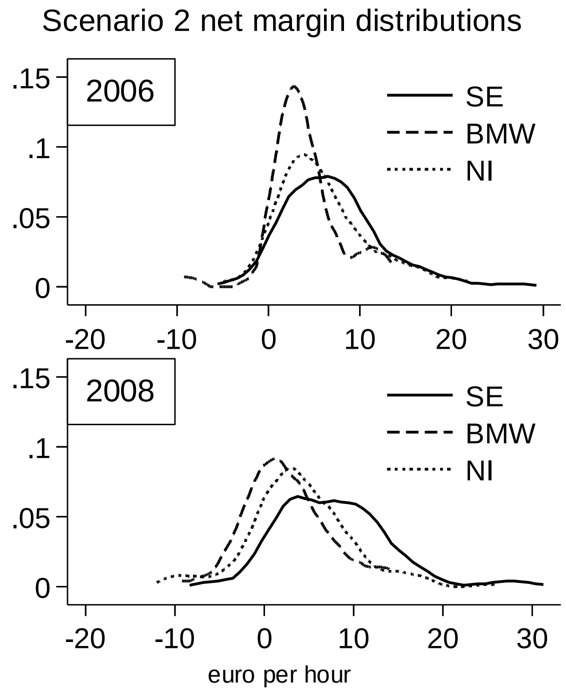
Scenario 2 equalises the average farm-gate milk price in Ireland and Northern Ireland by shifting the distribution of this price by the ratio of the averages calculated in each country.[12] The variability of output price within each country is left unchanged. This scenario removes the effects of the various forces which result in a price differential between the two countries as discussed in section 5.3, but it is worth noting that it implicitly assumes that the choice of input-output bundles remains essentially unchanged.

The effect of the price equalisation is to reduce the number of statistically significant tests in the IE-NI comparison, and to increase by one the number of rejections in the BMW-IE comparison. The NI and IE distributions changed very little in 2006, but the BMW has a more pronounced dip in the right tail and is slightly taller than in the previous scenario. Furthermore, the BMW-NI test rejects the null hypothesis in this year, albeit at the 90 percent level.

[12] That is, $p_{IE,t}/p_{NI,t}$ is calculated, where p is the average price per farm in each country for each year. Each farm's individually calculated average price (value of milk /milk equivalent litres) is then multiplied by this ratio for the Northern Irish farms, hence raising prices in NI such that $p_{IE,t}/p_{NI,t} = 1$ for each year. The other moments of the distribution will be unaffected by this procedure.

Table 5.6 Tests of distributions of net margin per hour—Scenario 2—price adjustment

Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.637	0.000	0.141
2000	0.001	0.631	0.002	0.460
2001	0.000	0.703	0.003	0.342
2002	0.000	0.156	0.000	0.068
2003	0.000	0.034	0.000	0.980
2004	0.000	0.228	0.000	0.075
2005	0.064	0.129	0.096	0.065
2006	0.044	0.074	0.038	0.403
2007	0.331	0.027	0.213	0.992
2008	0.000	0.127	0.000	0.075
2009	0.000	0.000	0.318	0.001
Count p<0.05	9	3	8	1



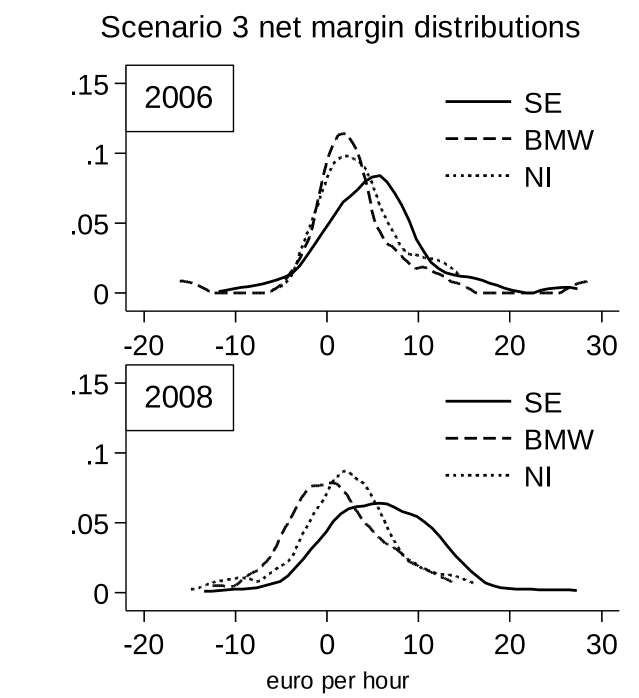
Source: Author's calculations

The 2008 plot shows the BMW region again taking a very similar shape to the NI distribution, although there is a small but definite leftward shift relative to the previous scenario. The t-test now rejects the null hypothesis on the basis of the different locations of the distributions, but the K-S test fails to reject the null due to the similarity of their shapes. For the reasons previously stated, we give precedence to the K-S test results over the parametric test. As in the previous scenario, the NI-IE test is definitive in both years, and the arrangement of distributions is the same. This scenario strongly supports a benefit from quota accruing to the BMW region which essentially balances structural benefits present in NI. The improvement is in the K-S test results for the BMW-NI comparison; they say that the differences in distributions in 2006 cannot be solely due to sampling, but one cannot rule this out for 2008 where they are much more similar.

The third scenario imputes a value for owned land on the basis of the rent rate for leased land in either country. Land rental rates reflect land quality in Northern Ireland, but in Ireland they also reflect capitalised quota values because quota has been tethered to land for most of the time horizon of the panel.

Table 5.7 Tests of distributions of net margin per hour—Scenario 3—no price adjustment, but net of opportunity cost of land

Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.052	0.004	0.004
2000	0.016	0.057	0.009	0.094
2001	0.000	0.085	0.000	0.075
2002	0.000	0.003	0.000	0.022
2003	0.000	0.001	0.000	0.006
2004	0.001	0.225	0.000	0.715
2005	0.040	0.319	0.068	0.110
2006	0.026	0.550	0.106	0.760
2007	0.689	0.207	0.829	0.823
2008	0.000	0.214	0.000	0.164
2009	0.494	0.279	0.319	0.312
Count $p<0.05$	9	2	7	3



Source: Author's calculations

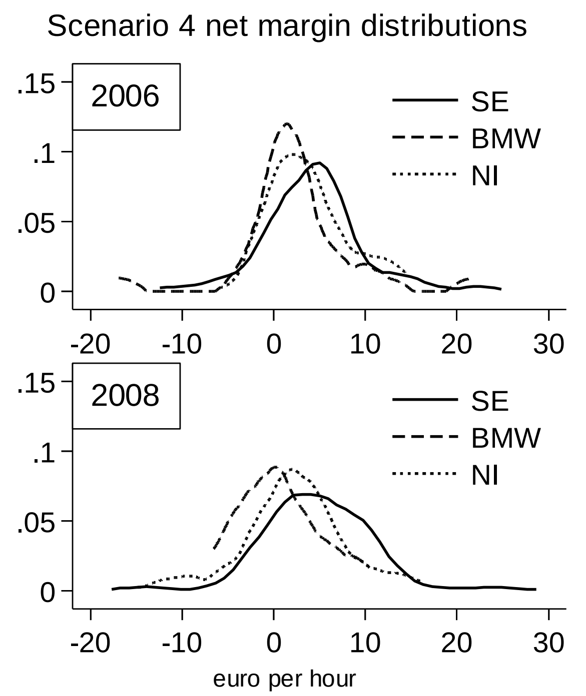
This scenario displays a more dramatic effect on the 2006 distributions, indicating that the opportunity costs of land are an important factor. In particular, the BMW and NI distributions are now nearly identical. The SE region is now slightly left skewed, which reflects the increased costs of land with capitalised quota value. Movements in the 2008 plot suggest that the creation of a market for tradable quota reduced these costs as land values adjusted. The SE distribution is nearly perfectly symmetrical now, and the right tail has become thicker.

The leftward shift of the BMW distribution is visible again, but it is also broader than the previous scenario, and a thickening of the right tail serves to blur the overall change in position which causes the K-S to fail to reject the null hypothesis. The main feature of this scenario is the loss of the very peaked BMW distributions, which forces a new interpretation of the move from non-tradable to tradable quota. Now the BMW and NI distributions are overlapped in 2006, but NI is to the right of BMW in 2008, i.e. the effect of a quota market is disadvantageous from the BMW region's perspective. However, the lack of statistical significance alleviates the contradiction presented by this scenario.

The fourth scenario applies both the price normalisation and the imputed land value. The BMW and NI distributions are again close enough to begin with to say they overlap in 2006. The SE region is now much more similar to NI in 2006, and tests for this comparison now also fail to reject the null hypothesis, so that we might say that all three distributions overlap, which would mean that we are able to statistically detect either agronomic or structural advantages in this year, although the distributions' relative positions on the plot is consistent with our expectations.

Table 5.8 Tests of distributions of net margin per hour—Scenario 4—price adjustment and net of opportunity cost of land

Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.023	0.003	0.002
2000	0.004	0.026	0.003	0.031
2001	0.000	0.218	0.002	0.367
2002	0.000	0.034	0.002	0.392
2003	0.001	0.001	0.000	0.026
2004	0.001	0.225	0.000	0.736
2005	0.105	0.194	0.116	0.076
2006	0.213	0.362	0.641	0.377
2007	0.532	0.130	0.641	0.893
2008	0.015	0.077	0.025	0.034
2009	0.000	0.002	0.319	0.004
Count p<0.05	8	5	7	5



Source: Author's calculations

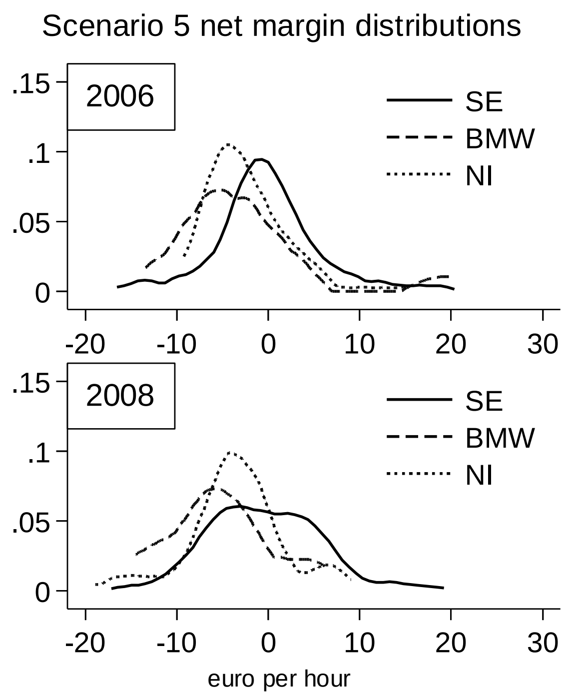
Whilst the results lack statistical significance in 2006, the movements in 2008 yield statistically significant comparisons for both regions of Ireland with NI. As in scenario 3, the BMW shifts to the left, but now a thinning of the right tail leads to a definitive result at the 90 percent confidence level. The SE distribution changes in a similar manner as it did in scenario 3, albeit with a slight right skew. The first two scenarios' bimodality is not present. Again, the NI distribution is little changed from the 2006 shape and location, hence supporting the change in quota regime as the primary cause of the movements in the other distributions.

The movements of the distributions in this scenario mirror those in scenario 3, but the result is stronger due to the significance of the tests in 2006 and 2008.The K-S and the t-tests reject the null hypothesis for both comparisons in 2008. The lack of statistical significance is at odds with expectations in the SE-NI comparison in 2006; we cannot rule out that the initial difference in these distributions is due to sampling alone. The overall arrangement is consistent with moving from outcome 6 (negative quota effect to outcome 3 (a positive quota effect which is outweighed by structural effects).

The fifth scenario more completely accounts for total economic costs. Opportunity costs are imputed for labour and farm capital, and these are reflected in the calculated margins. As is often the case when these costs are included, net margins are often negative, but the arrangement of distributions is similar otherwise. The BMW region is slightly left of NI, but it is broader and has a small hump in its right tail, and the tests fail to reject the null hypothesis. Therefore, the outcomes look approximately the same when taken over the entire distribution, i.e. the distributions are mainly overlapping. Unlike all the other scenarios, the SE regions distribution is more peaked than the BMW distribution; hence, there is less variability in net margin, and outcomes are more positive than for either of the other distributions.

Table 5.9 Tests of distributions of net margin per hour—Scenario 5—price adjustment and net of total economic cost

Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.011	0.008	0.001
2000	0.000	0.011	0.001	0.003
2001	0.000	0.016	0.003	0.027
2002	0.000	0.494	0.001	0.463
2003	0.000	0.005	0.000	0.006
2004	0.000	0.020	0.000	0.730
2005	0.000	0.515	0.000	0.995
2006	0.001	0.666	0.027	0.868
2007	0.121	0.461	0.270	0.184
2008	0.001	0.125	0.001	0.145
2009	0.000	0.208	0.000	0.035
Count p<0.05	10	5	10	5



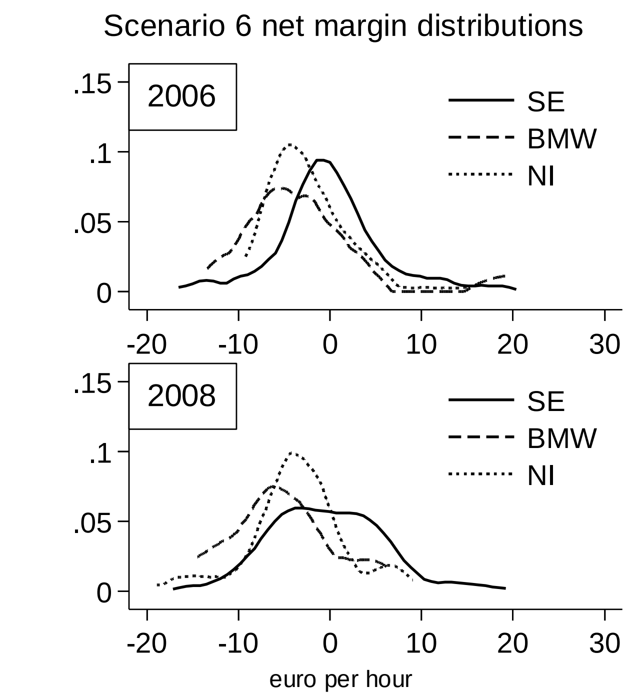
Source: Author's calculations

The effect of tradable quota here is unambiguously positive for the SE region. Its distribution has been stretched rightwards and flattened, with its' peak being pushed into the right tail of more positive net margins. NI sees a small dip in its right tail, and the left tail has thickened, so NI farms are moderately worse off, indicating that there may have been small effects from labour or capital opportunity costs in the changes in the 2008 distributions relative to 2006. The BMW's distribution loses the extreme right tail it had in 2006. Its left tail is thicker. There is now a notch on the right side of the distribution, and its main mass has shifted leftward. The BMW is definitively worse off under tradable quota in this scenario. This corresponds with a movement from outcome 2 to outcome 3 in Figure 5.3 which indicates a quota benefit which is outweighed by advantageous farm structures, but this conclusion is tempered by the lack of a rejection in the BMW-NI tests in 2008, although it would be statistically significant at a (non-standard) confidence level of 85 percent.

The final scenario adds in explicit quota income from the (direct) sale or leasing of quota. The normal definition of dairy output in the FADN methodology excludes these values, putting them instead under “Other output”. Quota costs (purchase, leasing, and taxes) are reflected in rents and interest payments (when quota costs are financed), so these costs have been present in the previous scenario. As these values are critical for the hypotheses we’re testing, we include them again here. There are very few non-zero incomes present in the data. This explains the fact that there is no discernible changes in the plots relative to scenario 5, and that the calculated p-values for the tests are all but identical. Consequently, the interpretation is unchanged from scenario 5 in terms of the direction of the change in the quota regime’s effect, but the mechanism now appears to be an indirect effect on land values rather than through direct quota transactions.

Table 5.10 Tests of distributions of net margin per hour—Scenario 6—price adjustment, net of total economic cost, and inclusive of quota income

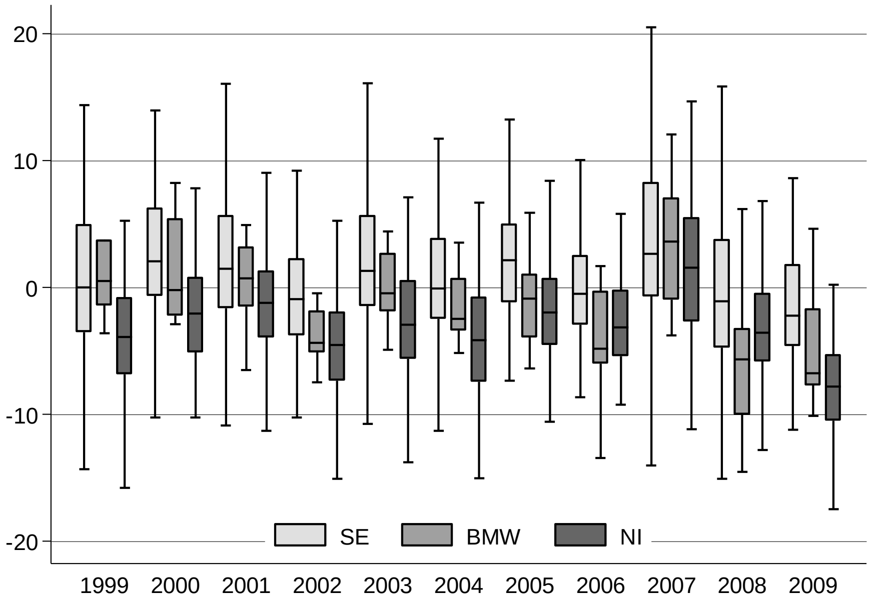
Year	K-S test p-values		t-test p-values	
	SE-NI	BMW-NI	SE-NI	BMW-NI
1999	0.000	0.014	0.012	0.003
2000	0.000	0.021	0.002	0.006
2001	0.000	0.028	0.009	0.077
2002	0.000	0.560	0.001	0.489
2003	0.000	0.008	0.000	0.013
2004	0.000	0.050	0.000	0.989
2005	0.000	0.515	0.000	0.934
2006	0.001	0.666	0.024	0.880
2007	0.121	0.461	0.277	0.187
2008	0.000	0.125	0.001	0.149
2009	0.000	0.208	0.000	0.035
Count p<0.05	10	4	10	4



Source: Author's calculations

The plots displayed thus far have selected two individual years from the 11-year time horizon available in the panel data. These years are close to the establishment of tradable quota in Ireland, but there are other reasons why they are more suitable than other years. The decoupling of support payments was enacted in 2005, so it is advantageous to give special examination to years which occur after this change in order to avoid conflating it with tradable quota's effect. Furthermore, the year's post 2007 witness increased price volatility, particularly in milk prices, so the choice of years must be undertaken with care. Figure 5.5 below illustrates the distributions of net margin calculated for scenario 6 via boxplots. The interpretation of the graphic is simple; a box—the length of which represents the interquartile range of the distribution—is plotted for each region in each year. 'Whiskers' are added above and below to represent the 95 percent confidence bounds of the distributions, and a small horizontal bar is added within each box to note the median of each distribution as a measure of central tendency.

Figure 5.5. Distributions of net economic margin per annum, inclusive of quota income (by analysis region)



Source: Authors' calculations

As can be seen from the graphic, the year 2008 just happens to be in line with historically ‘normal’ levels. The effects of global financial crisis—having occurred late in the year—are largely absent from this year’s data, but is acutely present in the 2009 data when the milk price collapsed.

The figure also reveals a few medium term trends. The relative positions of the SE and NI distributions appear stable over the time horizon, but it is evident that the BMW’s position gradually worsens relative to the other two regions. Furthermore, NI’s improved standing relative to the BMW is not due to positive movements of its own distribution relative to SE, but instead is wholly due to BMW’s declining situation.

5.7 Conclusions

This chapter set out to examine the effects of quota implementation on distributions of net margin and the choice of system set up. The analysis leverages a natural experiment in Ireland and Northern Ireland to examine these hypotheses directly using comparisons of the mean levels of input, output, and margins across countries over time, as well as comparing distributions through plots and non-parametric tests.

The results from the analysis of means across countries provide mixed support for the hypothesis that high margin over quota production environments support high-cost, high-yield systems. Northern Irish production systems are indeed higher cost and higher yielding than the average Irish farm set up, and since NI farms would also have a higher margin over quota due to a more plentiful supply of quota suppressing quota prices, this finding supports the hypothesis. However, the establishment of a market for tradable quota in 2007 should have reduced the difference in margins over quota in the two countries, and this should have been accompanied by some evidence of convergence of the two system types, but no such evidence is present in the data. It should be noted that the panel only extends through 2009, so there may not have been enough time for any structural changes to manifest themselves in the remaining observations post-2007.

A production function was estimated to assess the likelihood that the two countries' production technology does not differ due to, e.g. agronomic differences. The results of Chow tests soundly reject this hypothesis, and parameter estimates for minimum temperature and the combined value of land and quota suggest important role that differences in agronomy and quota policy play.

The analysis of net margins proceeded under several incremental scenarios. The initial scenarios which only consider cash costs suggest that the move from a restricted to a tradable quota regime has been beneficial for both the BMW region and the SE region, relative to the NI region, which was essentially unchanged. This supports the notion that the movements were in fact due to the policy change, and provides evidence in support of the hypothesis that tradable quota unambiguously improves farm incomes across the entire distribution of farms.

The later scenarios which account for opportunity costs provide a different story. Once these costs are accounted for, the direction of the effect of the policy change reverses for farms in the BMW which are made worse off. The SE on the other hand tends to benefit as the change in regime removes quota value from land rental.

Unlike the other scenarios, when the remaining economic costs are fully accounted for in scenarios 5 and 6, then the NI distribution also changes slightly, indicating that some effects related to the opportunity costs of labour and owned capital are also present which are independent of the change to tradable quota in IE. However, these appear small relative to the changes in the other distributions, so the loss of some of the experiment’s internal validity may be only minor.

The final scenario explicitly includes quota income in net margin calculations. Very few farms have non-zero quota income in either sample, and as a consequence the scenario changes very little relative to scenario 5. This indicates that the mechanism by which the change in quota regime affects net margin is an indirect one, and the similarity of scenario 3 with the final scenario suggests that this is most likely through the removal of quota values from land.

The later scenarios contradict the hypothesis of an unambiguous benefit to moving from restricted to tradable quota regimes. Such contradictory results concerning the effects of quota implementation are not uncommon, e.g. Zimmermann and Heckelei (2012) find that structural change is facilitated by more liberal quota in terms of limiting farm numbers, but that administratively handled quota regimes better encourage farm growth.

However, this particular contradiction may be partially explained by the fact that quota markets are 'ring-fenced' in Ireland. Hennessy et al. (2009) note that large differentials in quota prices exist between regions and prices in the BMW are particularly low, which mirrors the situation in Northern Ireland as being de facto quota-free. When combined with the loss of capitalised quota values in land transactions, this may be more indicative of a move from a quasi-tradable quota regime (through land transactions, and highly limited, centrally-administered quota market which existed before 2007) to a no-quota production environment. Guyomard et al. (1996) do specify a worsening situation as a distinct possibility for high cost producers, such as those which are present in the BMW and NI due to poorer agronomic conditions. A clear result from the latter scenarios—which account for opportunity costs as well as accounting costs, and which are therefore more in line with economic theory—is that the move to tradable quota has had differential effects depending on the region of Ireland; the BMW has worsened and the SE has profited. This is in line with Läpple and Hennessy's (2012) results concerning expansion potentials post-quota. This chapter's results also suggest that inter-regional transfers of production are on the horizon, and these will pose many challenges in years to come.

Chapter 6 The efficiency effects of grass utilisation

6.1 Introduction

The impending removal of milk quotas advances EU policy reform goals relating to WTO-style liberalisation and to increasing the economic viability of some kernel of commercial farm businesses within the farming population. There are, however, other sets of objectives in EU agricultural policy which may not encourage either intensification or consolidation of production. These include the areas of environmental protection, animal welfare, and rural development sustainability. In light of these competing objectives, and given that the dairy sector is set to expand in a post-quota production environment, it is useful to address the nature of that expansion.

Chapter 2 discussed the concentration and intensification of the dairy sector even during the life of milk quota policy. Furthermore, the increasing returns to scale found in the analysis in Chapter 4, as well as the structural differences with Northern Ireland found in Chapter 5 both support the notion that these processes will continue and possibly increase in the years after quota abolition. To the extent that these developments may be contrary to the environmental goals discussed in 2.2 as well as the implications for the distribution of farm incomes which result from the analysis in Chapter 5, there is a need to assess the viability of alternative models of dairy expansion. In Ireland, the most prominent competing model is one which focuses on improved grass management.

Research into effective and efficient management of grass swards suggests that improved grassland management practices may be a viable alternative to more intensive production strategies (Kennedy et al., 2005). Furthermore, Lovett et al. (2008) showed that some negative externalities may be reduced whilst simultaneously improving whole farm profitability. The specific externality in their study was GHG emissions and they used the case of Irish dairy farms in their stochastic budgeting framework.

The Lovett et al. report is just one study which uses data from experimental farms to establish efficient farm practices and their impact. Such experimental data provides strong evidence that grass can be employed in an efficient way when conditions such as those which were present during the experimental trial hold true in actual production environments. However, agricultural production is subject to stochastic shocks which may help or hinder production in a given year. Furthermore, experimental data often represent the best case rather than the average case in terms of farm level resource endowments—soil quality being just one example. Peeters (2008) illustrated that European grasslands exhibit a high variability in management styles, natural endowments, and hence productive capacity.

These analyses point to a need to establish to what extent grass input is associated with the efficiency of production in livestock systems. The present work contributed to the body of research by conducting an analysis of the effect of grass utilisation on enterprise level efficiency.

This work occupies a unique niche between the scientific and economic studies on the topic which were cited above. Economic studies can lack internal validity due to the lack of an experimental design, their reliance on observational data, and their need for many assumptions. However, scientific studies may lack external validity in attempting to generalise their results. This chapter starts from an hypothesis generated from the technical literature on the productive capacity of grass, and it statistically tests this using a high quality observational dataset in the FADN data. The hypothesis tested is that choosing a higher level of grass input in a specialist dairy system results in a greater level of efficiency. Like all economic production studies, the model used is informed by the economic theory of the firm, but it relaxes the assumption of firm efficiency through its specification of a SFA model which explicitly models firm efficiency.

The remainder of the chapter is organised as follows: Section 6.2 provides a look at the existing literature on dairy efficiency**;** Section 6.3 reviews the relevant theory, whilst section 6.4 describes the details of the methodology. Section 6.5 describes the panel of data constructed for this analysis. Section 6.6 reports the model's estimates, with a discussion of conclusions and implications rounding out the chapter in the final section.

6.2 Survey of the literature of dairy efficiency

It is important to understand that, whilst there are many works which examine both technical efficiency and cost efficiency, there is a gap in the literature where the efficiency of grass utilisation is concerned. The scientific studies reviewed above point towards possible benefit in terms of technical and cost efficiency, but such studies may lack external validity, i.e. their experimental design may not be generalizable to the average situation faced by dairy farms. Conversely, observational studies which may be more generalizable seldom examine grass utilisation as a driver of farm level efficiency. This section provides a view of that literature which is closest to this specific research question.

The new emphasis on grass-based production has roots in both the commercial and environmental spheres. On the one hand grass-based systems may introduce a lower cost structure for production in a country such as Ireland, with its competitive advantage in grass production both in the present (Jesse et al. 2007) and under likely future climate change scenarios (Fitzgerald et al. 2009). This would improve the competiveness of the Irish dairy sector. On the other hand choosing a grass-based system may have beneficial environmental effects under the right conditions and management (Kristensen et al. 2005).

If targets for agricultural emissions are set and enforced equally across the EU, or if consumers place a sufficiently high value on more environmentally friendly dairy products, then Ireland could find that this also increases its competitiveness. Thornton and Herrero (2010) attempted to quantify the GHG emissions abated through the adoption of improved grasslands in the tropics using a partial equilibrium agricultural commodity model combined with a GHG conversion model. At $20 per tCO_2-e, they estimated that the value of abated and sequestered emissions under their “optimistic but plausible" scenario could be worth $1.3 billion.

Saunders and Barber (2007) compared the U.K. and New Zealand dairy sectors in terms of energy use and GHG emissions on a per unit of output basis using a life cycle assessment methodology. They found that New Zealand enjoyed an advantage; milk solids produced in the U.K. had 34 percent more emissions per kg (or 30 percent more per ha) than those produced in New Zealand even after accounting for the additional energy and GHG emissions associated with transport. This is a reflection of the less intensive production systems employed in New Zealand.

Ledgard et al. (1999) used a 3 year study on experimental dairy farms in New Zealand to examine the effect of differing levels of nitrogen application on mixed clover and grass pastures to N-efficiency. They found that a pasture system whose sole reliance on N_2-fixation as its main source of N was relatively efficient at 52% of N output in products relative to N input. They also found that on a 400 N farmlet, the N-efficiency was still favourable as compared to intensive dairy systems in England and the Netherlands. Ledgard et al. (2009) found that at similar inputs, mixed clover and grass pastures can be more N-efficient than grass-only pastures, but they also stipulate that 'other management practices on the farm [...] can have a larger overall effect on environmental emissions than whether the N input was derived from fertiliser N of from N_2-fixation.'

Shalloo, et al. (2004) also constructed a model which examines the productivity of pasture based spring calving dairy systems on high rainfall, heavy clay soil versus those which operated on lower rainfall, free draining soil. They then quantified the difference in their economic potentials applying a Monte Carlo simulation approach to the observed data. They found that under a 468,100 kg EU quota scenario, profitability on the lower-rainfall and free-draining soil farm was €27,417 when differences in yield per cow were allowed. When those yields were held constant for both farms the difference in profitability was still €19,138 in favour of the well-drained soil. The authors drew the conclusion that production may not be viable on heavy clay soil types in Ireland in the future.

Kristensen et al. (2005) surveyed the literature to examine the link between grassland management practices, environmental and production outcomes. They called for more research in the areas ranging from nutrient utilisation, to the interaction of N and carbohydrates in dairy cattle nutrition, to improved knowledge of how to manage grassland taking into account herd size and the interactions between technology and grassland management".

Hopkins and Del Prado (2007) reviewed the literature regarding the potential effects of climate change on grassland yields. They found that there was a potential for increase herbage growth and for the new conditions to encourage legumes more than grasses. However, grassland agriculture can also contribute to GHG emissions, and as a result they claimed that more effort has to go into understanding management practices which mitigate these emissions “in a holistic way that also considers other pressures”. In the same vein, Fitzgerald et al. (2009) utilised a simulator to anticipate the impacts of climate change on low-cost, grass-based dairying in Ireland. The simulation was carried out for 11 locations for both well drained and poorly drained soil types, and the changes in system properties (e.g. stocking rate, grass yield, etc.) over the simulation period were observed. The authors conclude that Ireland's grass-based dairy systems should be able to adapt to the future climate well. In a similar study carried out for the Swiss plateau, Finger et al. (2010) found that climate change increases risks in grassland production.

Elsewhere, Herrero et al. (1999) constructed a bio-economic model using simulation and mathematical programming techniques to represent grass-based dairy systems. The resulting model was applied to highland dairy performance in Costa Rica, and compared observed data to the optimal outcome detailed by the model. The model's attention to pasture based systems was pertinent, as was its attention to regional context in the biological aspects.

As discussed in Section 6.2 , there have been comparatively few studies which use cost frontiers in the literature of efficiency measurement, particularly as it relates to agricultural production. Mosheim and Lovell (2009) did specify a cost frontier in an analysis of economies of scale and efficiency on U.S. dairy farms. They find that scale economies were underestimated when allocative efficiency and TE were not properly accounted for. They also contend “that scale economies were far more crucial”.

Papers which used FADN data to analyse cost efficiency (CE) include Maietta's (2000) decomposition of CE on Italian dairy farms, Pierani and Rizzi's (2003) symmetric generalised McFadden cost function for Italian dairy farms, and Coelli, Lauwers, and Van Huylenbroek's (2007) estimation of environmental efficiency using a cost frontier framework. The Maietta paper found an underutilisation of both forage and feed relative to labour input in its sample, whereas Pierani and Rizzi focused on pre-quota and post-quota measurements of efficiency it Italian dairying; they found generally low levels due to poor TE.

Coelli, Lauwers, and Van Huylenbroek (2007) use a sample of Belgian pig farms to estimate environmental efficiency to conclude that "that a substantial proportion of nutrient pollution on these farms can be abated in a cost reducing manner". The author is not aware of any other studies of CE which examine the efficiency effects of grass input in the context of dairy production, so in this respect this work is novel.

A large number of significant variables affecting farming TE levels have been confirmed. Kumbhakar et al. (1989) found that dairy farm efficiency increases with farm size and farmer education. For the Spanish dairy sector, Alvarez et al. (2006) found that efficiency increases with higher stocking rates (cows per hectare). Hadley (2006) explored the effects of a large number of potential variables for eight separate farm types in the UK. Among his results, it was found that the most efficient dairy farms have low debt to asset ratios, have high subsidy to gross margin ratios, have high tenancy ratios (more owner occupied land) and were also less specialised. In an Irish context, O'Neill and Matthews (2001) explored the variables that affect the efficiency of Irish agriculture using aggregate measures. They found that farming in the east of the country, larger household size and higher levels of borrowings were positively associated with technical efficiency, while having an off-farm job and smaller farm size were negatively associated with efficiency. Furthermore, Boyle (1987) and O'Neill et al. (2002) found that contact with the advisory service was associated with higher levels of efficiency.

Paul et al. (2004) used SFA and deterministic DEA models to compare the competitiveness of small family farms relative to large industrial farms using a panel of farms in corn belt of the U.S.A. Competitiveness was measured in terms of scale economies and technical efficiency. Their analysis concludes that small family farms were both scale inefficient and technically inefficient.

Nehring et al. (2009) researched the competitiveness of small farms in the U.S.A. using panel data ranging from 2003 to 2007. They also used a SFA model to compare the performance over time of conventional and pasture technologies which they identified using a binomial logit model. They too found that large conventional farms won out in most economic measures.

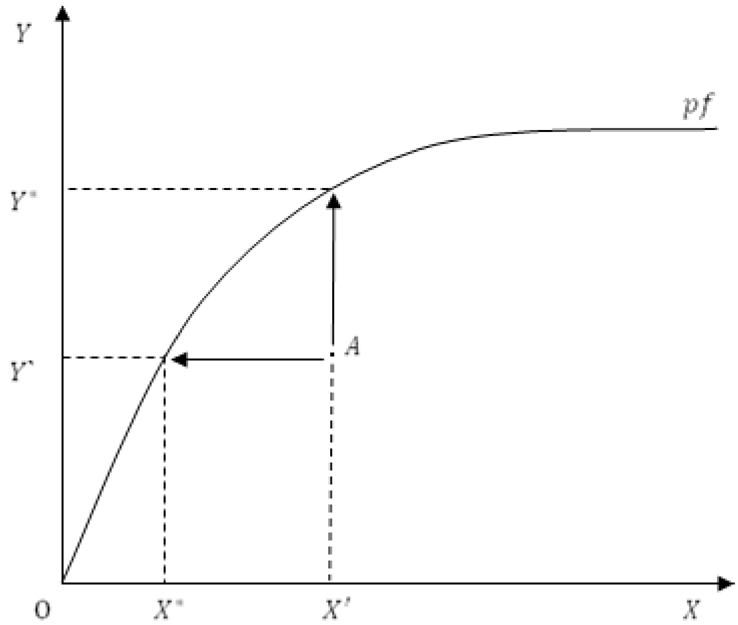
6.3 Theory and research question

The research topic at hand requires an in depth definition of the term "efficiency", which can mean different things in different context. The term as it is applied in this chapter relates to the definition commonly known as the Debreu-Farrell definition of efficiency. This section takes the reader through a discussion of Farrell's concept of two types of efficiency—technical and cost—and relates this to the microeconomic framework given in Chapter 5, as well as developing specific hypotheses of the effect of grass utilisation on efficiency.

Farrell (1957) pointed out the inadequateness of the average productivity of labour as a measure of efficiency, and he also expressed concern that such a measure could 'have unfortunate effects on economic policy.'

A better approach is the construction of a type of index which takes into account all inputs (i.e. not just labour, as in average labour productivity). Farrell noted however, that this approach had been attempted by his forerunners and colleagues, and that the construction of an index is not an easy task. However, Farrell did succeed in creating a measure of efficiency which allowed for multiple inputs in the production process. This has come to be known as the Debreu-Farrell measure of efficiency.

Figure 6.1 Input and output orientated measures of technical efficiency



Source: Carroll et al. (2008).

Kumbhakar and Lovell (2000, p.43) give the formal definition of the input and output orientated Debreu-Farrell efficiency measures;

Definition 6.1: An input-oriented measure of *technical* efficiency is a function

$$TE_I(y,x) = \min\{\theta : \theta_x \in L(y)\}$$

Definition 6.2: An output-oriented measure of technical efficiency is a function

$$TE_O(x,y) = [\max\{\phi : \phi y \in P(x)\}]^{-1}$$

where $L(y)$ and $P(x)$ are feasible input and output sets respectively. In the case of output orientated efficiency defined above (Definition 6.2) , i.e. that measure which was employed in this thesis, this is simply the proportion of observed output relative to maximum attainable output from a given input vector.

The function ranges over the interval $[0,1]$, and its difference from unity can be interpreted as the fraction of output which is lost to inefficiency. This is summarised graphically in Figure 6.1, where the fraction of the distance to the production frontier pf achieved by the farm at point A is $\overline{0\mathrm{Y}'}/\overline{0Y^*}$, which is just $Y'/Y^* = TE_\mathrm{O}$.

Cost Efficiency

The real contribution of Farrell's paper was the decomposition of efficiency into technical efficiency (TE) and allocative efficiency (AE) using a cost frontier. A cost frontier relates total expenditure to the level of output and to input prices. A generic function could thus be written

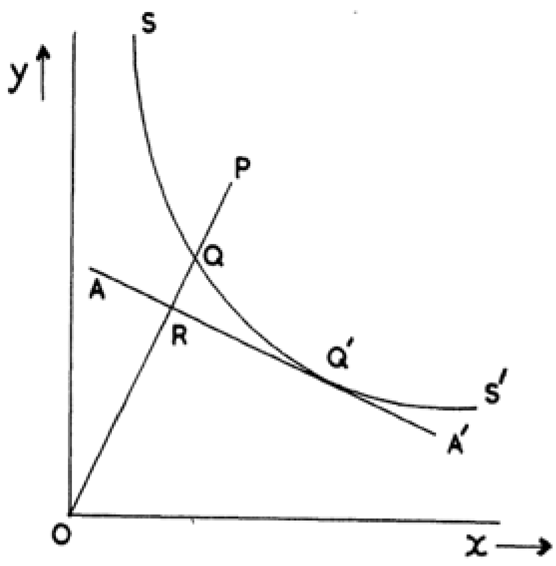
$$E = c(y,w)$$

with E being expenditure, $c(\cdot)$ being the cost function, and the arguments to the cost function being output level (y) and input prices (w). A cost frontier, i.e. the cost function pertaining to the efficient production only, switches the equality operator to an inequality operator

$$E \geq c(y, w)$$

in recognition of the fact that this function gives the minimum cost possible for a given output level and for a vector of input prices. Actual expenditure must be—at best—equal to minimum cost, but in most cases it will be greater than this value. Farrell (1957) depicts just such a cost frontier in a two input commodity space, which is reproduced in Figure 6.2 below.

Figure 6.2 Farrell's isoquant in two-dimensional input space



Source: Farrell (1957).

Farrell's nomenclature uses y as a separate *input* here, with the isoquant sketched representing a level set of input bundles producing the same output as per the definition of isoquants in the standard theory. He reasoned that if the so called efficient production function which generated this isoquant were known in practice, it could provide a benchmark for other firms' observed input-output sets. The isoquant SS' represents all minimal combinations of inputs which could produce a given level of output. Now suppose that at point Q an efficient firm were able to produce the same as the firm located at point P. The measure of TE which Farrell proposed would then be equal to the ratio $0Q = 0P$. Furthermore, the curve AA' represents the trade-off in terms of the costs of the two inputs; it is the isocost line which has the slope that is equivalent to the ratio of the two input costs. The new efficient point would then be Q' instead of Q, and AE is then given by the ratio $0R = 0Q$, which is the fraction of costs faced by a firm producing at Q' relative to those faced by one at Q (by the nature of isocost lines). Finally, Farrell defines a measure of overall efficiency—understood to be CE—as the product of AE and TE, a quantity which is equivalent to the ratio $0R = 0P$.

Graphically, one can readily see that the improvement in overall efficiency (and thus costs of production) is composed of the improvement in technical efficiency—a movement from P to Q—and allocative efficiency—a movement from Q to Q'.

Farrell's 'efficient production function' is known as a production frontier in modern terms, and the isoquant which results from the production frontier is a cost frontier known to exist by virtue of duality theory. When one considers 'overall' efficiency in the context of a cost frontier, one speaks about CE. Hence, CE is composed of both TE and AE, and it follows on from this fact that for all firms $TE \geq CE$ because AE will also be bounded $[0,1]$.

There is a symmetry to the discussion of efficiency given above and that of profitability given in section 5.2. Farrell's isoquant is just the same isoquant which underpins the profit functions from Chapter 5, and the production frontier from this section is assumed for every farm (over the long run) by the dictates of profit maximisation in a competitive industry, i.e. the no quota scenario, because neoclassical theory assumes efficient firms. The SFA models test this assumption by setting up a null hypothesis that the data show no evidence of inefficiency via a comparison of variances for the u and v terms.

If one imagines the two inputs in this commodity space to be grass and other feeds then one is left with a graphical representation of the chapter's main hypothesis, i.e. that increasing the ratio of grass to other feed input results in improved efficiency. There are four possible outcomes which can be interpreted. Firstly, grass may be efficiency improving for TE and CE, and this would be represented by a movement towards the isoquant from some point lying to the 'northeast' of it, whilst also moving towards the correct input bundle on the isoquant itself, i.e. getting closer to the tangency in the diagram. Second, grass may improve TE but worsen CE, which moves the point towards the isoquant, but away from the tangency point. A third possibility is that grass worsens TE, but improves CE. This moves the point off the isoquant, but in a direction that brings it towards the tangency point. Finally, grass may worsen both TE and CE, and this would be represented by a movement away from both the tangency point and the isoquant more generally.

The imposition of milk quotas may be understood to have caused farms to revert from long-run cost curves to short-run cost curves (Guyomard et al, 1996). Since some factors are fixed in the short-run, cost minimisation will occur through manipulation of variable costs. The chief variable costs in dairy production are purchased feed and fertiliser. The studies cited in section 6.1 demonstrate that grazed grass is the least expensive feed source in Ireland, and potentially so in other parts of the EU. Therefore, it is reasonable to hypothesise that increased grass utilisation should be associated with improved CE through some level of substitution away from purchased feeds, but effects on TE are ambiguous.

6.4 Methodology

This section describes the methods used to estimate efficiency, be it TE or CE, and to estimate the efficiency effects of grass utilisation for both types of efficiency. Interest lies in the farm-level efficiency effects of grass, so a microeconomic approach was taken, and in particular a SFA model was used due to its strength in explicitly modelling randomness in the estimated frontiers (see 1.3). A production frontier was specified to estimate TE, and a cost frontier was used for the CE estimates.

Frontier functions were estimated and used to predict the effect of increased grass utilisation on efficiency levels using the single step Battese and Coelli (1995) variant of the SFA model. Recall from section 4.3 that the model is defined by the follow equations:

$$\ln y_{it} = \mathrm{B}_0 + \sum_{k=1}^{K} \mathrm{B}_k \ln x_{kit} + v_{it} - u_{it} \tag{6.1}$$

$$u_{it} = z_{it}\delta + w_i \tag{6.2}$$

where y is output, x_k is the k$^{\text{th}}$ input, v is the stochastic term, and u is the inefficiency term in ((6.1). This is a panel model, so the reader will note the subscripts i and t indicate individuals (farms) and time (year) in this specification. The subscripts on the term u_{it} are consequential because they indicate that the inefficiency term is not only specific to a particular farm, but also to a particular time on that farm, and hence the farm is allowed to become more or less efficiency as the years progress.

The efficiency effects equation ((6.2) is simultaneously estimated with the frontier in (6.1). Here, the environmental variables, i.e. drivers of efficiency, are denoted with z, and δ is the vector of parameters which describe the drivers' effects.

An estimation of TE is an intuitive place to begin the analysis, both because it is specified in terms of physical quantities of inputs and output, and because it does not require any behavioural assumptions. However, if one is willing to accept the assumption of cost-minimising behaviour amongst dairy farmers, the theory presented in the previous section can provide testable hypotheses to examine.

Equation (6.1) above describes a production frontier, but the model can be converted to a cost frontier. This is accomplished simply by changing the sign of the u term to positive, and by choosing the appropriate left and right-hand side variables as shown in the generic cost frontier from the previous section.

Furthermore, equation (6.1) defines the frontier using the Cobb-Douglas functional form, as this was the functional form chosen for this analysis. The relative strengths and weaknesses of the Cobb-Douglas functional form are discussed in section 4.3. This choice eases the interpretation of the model's coefficients, and it also helps to ensure its theoretical consistency.

The Battese-Coelli model assumes a truncated-normal distribution for the inefficiency term with the point of truncation being a function of 'environmental variables'. These drivers of efficiency may or may not be part of the production (cost) function themselves, but they do affect the development of average efficiency by altering the truncation point of the inefficiency distribution, and hence its centre of mass.

Kumbhakar and Lovell (2000) explain that cost frontiers can distinguish between the different fixities of inputs, and this allowed for the estimation of a variable cost frontier. This was interpreted as the minimum cost achievable in the short-run where certain inputs were considered fixed. This was appealing because, although the panel of data extends over 9 years, the average duration of reporting in the sample was generally much shorter (2.9 years). All costs other than cattle purchase, feed, and fertiliser were considered as fixed in this specification.

Country specific frontiers were estimated to construct the measures of TE and CE. This approach recognised that production in each country depends on country specific unobserved variables, e.g. policy differences and climatic conditions. Therefore, this approach gave a better representation of the effects of grass on efficiency given these country specific differences.

A trend variable was also specified to capture technical change. This term represented so called Hicks' neutral technical change, i.e. whereby the rates of substitution between inputs were deemed constant over time and irrespective of movements in the frontier.

6.5 Data

The strengths of the FADN data were given in section 3.3 , as was the justification of the use of such data in a international comparative study. As this chapter is an example of such a study, the FADN was the primary source of data used in this analysis.

The countries studied in this analysis were confined to Germany, France, Ireland and the Wales. The period of study ran from 1999 to 2007, yielding an unbalanced panel of a maximum of 28,730 observations of 7,704 farms which were categorised under the

FADN general farm type of Specialist Dairying. Farms stayed in the panel for an average of 3.7 years, but this differed across countries; mean duration ranged from 2.3 years in the case of France to 5 years in Ireland.

The research focused exclusively on the sources of efficiency in the dairy sector in the EU. This is not meant to imply that dairying is facing an entirely unique situation with regard to CAP reforms. On the contrary, recent and impending changes in policy and market conditions within the EU are likely to affect all livestock systems. However, the impact on the dairy sector has been more severe than in beef and sheep systems, and this is expected to continue to be the case in the coming years.

Furthermore, the methodological approach itself demands that the selected farms be fundamentally comparable in some way. That the dairy sector produces highly homogenous products relative to other livestock systems facilitates comparison across countries and regions. A similar analysis becomes far more problematic at the whole-farm level or in other livestock systems where the multi-output nature of the enterprise is more pronounced.

The analysis was confined to the specialist dairy sector as defined by the FADN. These farms derive at least $2/3$ of their standard gross output (SGO) from the dairy enterprise on the farm. However, there will be other enterprises present on the vast majority of even these specialised farms, necessitating an allocation of cost categories as discussed in section 6.4. This sample differed from the one constructed in the FADN's Annual Dairy Report due to the exclusion of less specialised dairy farms.

A log-linear model specification was employed, therefore it was necessary to address missing and zero valued observations of the modelled variables. Such observations were dropped from the analysis; they represented a relatively small proportion of the sample.

The FADN data available at the time did not contain quantity information for the inputs to the frontier function, but there was expenditure information. Coelli et al. (2005) outline the procedure for using appropriate price indices to deflate expenditure data as a proxy to quantity information on the inputs. Following their lead, several input specific price indices which are published by Eurostat are chosen as the measure of input prices. However, price indices had another role in the estimation of the cost frontier analysis.

The estimation of cost frontiers imposes some additional data requirements on the analysis. Specifically, cost frontiers require data on input expenditure, output quantities, and input prices (Kumbhakar and Lovell, 2000; p. 131). Since the FADN data did not contain quantity data for all inputs, it was not possible to generate observation specific prices for the cost frontier. Therefore, price indices were also used directly in the specification of cost frontiers. There was a complication here in that these indices were aggregates at the country level, so any regional or farm level variation in prices was absent from the model. However, market prices for inputs and outputs were determined on the global markets for each commodity, so most farms were likely to be price takers. Furthermore, although price levels may have considerable variability across farms it was plausible that changes in levels were more homogenous, thus alleviating some concern regarding the use of price indices.

Table 6.1 Whole-farm summary statistics

	Mean	S.D	Min	Max
Output (litres)	312,733	310,759	3900	6,925,000
Specific Costs (€)	44,361	49,489	367	1,316,278
Herd Size (LUs)	50	41	3.5	922.5
Farm Size (ha)	58	44	5.27	811.45
Forage Area (ha)	50	38	1.21	792.4
Labour (hours)	3,851	1981	400	48620
Purchased Feed (€)	19,914	25,489	0	530542.3
Fertiliser* (€)	5,427	5,622	0	177618
Buildings (€)	69,614	75,826	0	1628344
Machinery (€)	58,611	56,747	0	1185871
Grass ratio*	2.00	1.730	0.01	10.01
Specialisation**	8.12	1.466	0.54	126.47

* See table 6.2 for definition
** Dairy gross output/Total gross output
n = 28730 (most expansive sample modelled)
Sample size varies by model due selection and 0 values

Source : FADN data

Table 6.1 presents summary statistics of modelled variables across all countries and time periods. As might be expected in a panel which covers multiple countries over a number of years, the variables exhibit a large degree of variability. Only the labour variable has a standard deviation which is appreciably lower than it's mean value. Furthermore, the minimum values for direct cost expenditure categories reveal that the largest sample used contains zero-valued observations for these variables. These observations were dropped for the production model where they appear as regressors, but they were retained for the cost model where those variables were not part of the estimated function.

Table 6.2 breaks out this sample on a country by country basis. Structural differences in the countries are apparent at mean values of output; the Welsh sample has a mean level of output per farm approximately three time that of the other countries in the sample.

Specific costs are also larger in Wales by a similar factor, but the fact that herd size, farm size, and forage area are only double levels in other countries reveals the higher degree of supplemental feed reliance which exists there.

The grass ratio variable was constructed to proxy grass utilisation. The variable is highest in Ireland and Germany, lower in France, and at its lowest level in Wales. This is more in line with technical knowledge of production systems in the various countries as compared to the feed ratio alone, which puts the German level above the Irish level and which fails to reflect the higher level of arable feeds which exist on the continent.

Table 6.2 Whole farm mean values of selected variables

	Germany	France	Ireland	Wales	Atlantic Plains	Central Europe	Whole sample
Output (litres)	270,549	245,712	235,085	642,805	303,088	316,669	312,519
Specific Costs (€)	37,670	32,895	32,863	97,160	41,996	45,368	44,338
Herd Size (LUs)	41	41	45	96	53	48	50
Farm Size (ha)	49	66	48	89	59	58	58
Forage Area (ha)	22	30	24	47	29	27	28
Labour (hours)	3,672	3,084	3,713	5,784	3,830	3,860	3,851
Purchased Feed (€)	21,296	17,273	17,650	58,662	23,224	26,015	25,162
Fertiliser* (€)	3,665	5,445	6,711	9,938	7,257	4,623	5,428
Buildings (€)	83,257	65,558	61,432	39,045	60,288	73,774	69,654
Machinery (€)	67,255	50,068	28,200	76,103	40,741	66,444	58,591
Feed ratio**	0.31	0.21	0.23	0.14	0.21	0.27	0.25
Grass share of forage UAA	0.75	0.77	0.99	0.94	0.91	0.78	0.82
Grass ratio***	0.23	0.17	0.23	0.12	0.19	0.20	0.20

* Whole farm expenditure on all fertilisers and soil improvers

** Whole farm value in euro of Home-grown feed for grazing livestock divided by value of all feed for grazing livestock

*** Feed ratio x Grass share of forage UAA (proxy for grass utilisation)

Source : FADN data

Variable construction

FADN data itemises costs on a whole farm basis only, and some method of allocating these costs to the specific enterprises analysed in this research has to be attempted. Allocations followed the methodology set out by Donnellan et al. (2011, 36–39) and these usually progressed on the basis of either livestock ratios or output ratios (details provided in appendix).

All of the variables in the specified models were log-transformed—with the exception of the dummy variables—to accommodate estimation in the ML framework. This also had the effect of reconciling differences in scale between variables, e.g. between hectares of dairy forage and annual litres of milk production. An advantage of the Cobb-Douglas functional form is that the resulting parameter estimates can be interpreted as elasticities, such that percentage changes in the variables resulted in a change in the dependent variable of β percent.

The measure of grass utilisation was constructed by dividing the quantity of Home-grown feeds for grazing livestock by the quantity of all feeds for grazing livestock. Home-grown feeds included grass, but also arable crops, fodder root crops, and milk fed to calves, as well as some other input categories. Furthermore, the denominator included any feed input which was purchased, so it included not only concentrate feeds, but also grass input and any other input category in the numerator so long as it was purchased. A maintained hypothesis was that this measure was a reasonable proxy for grass input, at least in Ireland, but without data on grass quantities it was impossible to verify this point.

Measures of capital (buildings and machinery) were deflated by the corresponding Eurostat price indices to approximate actual quantities. The other variables in the models were measured in real quantities, so no other deflation was required.

The dependent variable in the model of TE was the value of cows' milk and other milk products in terms of litres of milk equivalents. This variable also entered as an independent variable in the model of CE. Dairy farms produce beef as a by-product (calves in excess of replacement), but there was no accounting for this output in terms of milk equivalents in the variable, so this output was ignored.

No data on soil quality were available for this analysis, but the FADN data did categorise farms into altitude zones, and this was used as a rough indicator of soil and climate quality in the present study. The levels of this variable indicate altitudes up to 300 metres, from 300 to 600 metres, and more than 600 metres above sea level (zones 1 to 3 respectively). There were a small number of observations for which a value of this variable was not available, and these were excluded from the analysis. The altitude zone variable was then converted to 3 dummy variables (one for each zone); two of these were included in the model specification, with zone 1 (under 300 metres) defined as the base level against which the others were compared. It was assumed that higher altitudes were associated with poorer soil and climatic conditions on average. Such an assumption is typical amongst technical experts working in this field when soil quality data are not available.

Although milk yield is often used as an indicator of technical efficiency, it is important to note that it was not included in the models put forth here. Inclusion of milk yield on the right hand side of the model introduces a high degree of endogeneity when the response variable is milk output, and hence the resulting frontier parameter estimates would be too biased to be useful. This is due to the definition of milk yield; it is milk output (i.e. the dependent variable) divided by dairy cows (i.e. herd size). The fact that herd size was included in the model means that adding milk yield would also increase any multicollinearity in the model (correlated regressors) which reduces the model's statistical efficiency. However, this problem is very much of secondary importance when compared to the bias problem caused by endogeneity.

An alternative approach may have used milk yield as the measure of output on the left side instead, but then herd size would have to be removed from the right hand side (endogeneity again). This would have been unnecessary and disadvantageous; specifying herd size as a regressor sufficiently controlled for its effect on output, and the parameter values associated with this variable was of interest.

Furthermore, milk yield is one of many possible indicators of technical efficiency, but the measures of TE generated by both SFA and DEA models are superiour. This is due to the fact that the SFA and DEA measures consider the TE of a productive process relative to all inputs. Milk yield is a partial productivity indicator; it does not consider changes to other input levels (e.g. fertiliser), and it is defined in scaled units. Technical efficiency is a pure number (a ratio) and it considers the entire vector of inputs simultaneously.

6.6 Results

This section presents the results of the various model specifications estimated. Parameter estimates for the model of TE are presented first, followed by the results for the model of CE.

Production model: drivers of TE

The results of the four models were presented in Table 6.3 below. The parameters estimated for the production frontiers' inputs in each country were nearly all statistically significant and were all positive with the exception of dairy forage area which was negative in Ireland and Wales, although it was not statistically significant in Wales. This was a theoretical violation of monotonicity. Measures of land have a history of returning such violations in an Irish context (Carroll et al., 2008).

The control variables specified in the frontier functions, i.e. the altitude dummy variables and the time trend were all statistically significant at the 95 percent confidence level, and their signs pointed in the expected direction. The frontiers for farms in higher altitudes generally yield less output for any given level of input, and the frontier was moving outward (more production per input) over time.

The parameter lambda measures the variation of the inefficiency term u_i relative to the noise component v_i of the error term. The p-values associated with this term test the hypothesis that there was no efficiency present in the data, and this was rejected in every case. The components of lambda were also tested, and each test also rejects the null hypothesis of equality with zero, i.e. both inefficiency and statistical noise were present in the data.

The simultaneous inefficiency effects model had two regressors; the constructed measure for grass utilisation (the feed ratio) was specified alongside specialisation as captured by the ratio of dairy output in gross output. Negative signs (interpreted as a positive relationship with efficiency) were observed for this parameter in all of the frontiers, although the effect was not statistically significant in Germany. The efficiency improving effect was strongest in Ireland, as would be expected.

The specialisation variable was also efficiency-improving, but it was not statistically significant in Wales. This comports well with economic theory. The same variables were included to model the variance of the inefficiency term, but these had to be excluded in the Irish and Welsh models to allow them to converge. Both the grass ratio and specialisation tend to increase the variability in u.

Grouping farms by country makes sense for comparing the effectiveness of country specific policies as long as these farm populations are fundamentally comparable. It may be more realistic to assume that farm systems adapt to climatic and soil conditions, so similar models were estimated after regrouping the samples by regions falling into bio-economic zones. The results of these more agronomically orientated models are similar; the level of grass utilisation and specialisation improve efficiency in both the Atlantic Plains, and in the Central European zone, as well as for all regions pooled together. Again, land violates monotonicity, but this is only statistically significant in the Central European zone.

The variance of u could not be modeled for the Atlantic Plains, but the negative signs for specialisation in Central Europe and for the grass ratio in the whole sample differ from the results in Table 6.3, where the variable are always increasing the variability. In the Central European model being more specialised in milk production reduces the variability in the inefficiency term, whereas for the sample taken as a whole, increasing the level of grass utilisation decreases that variability.

The variance of the stochastic noise component (v) was also modeled where possible. It was specified with a single trend variable which simply marked the passage of each year. Where this parameter was possible to estimate, the resulting parameter was always statistically significant at the 99 per cent confidence level, and it was always positive, hence v became more variable as time went on. White's robust standard errors are applied to all the models in light of this heteroscedasticity.

Table 6.3 Results of country specific production models

		Germany			France			Ireland			Wales		
No. Observations		13,228			4,318			3,551			4,427		
No. Farms		2,981			1,861			710			1,574		
Avg. Duration (years)		4.4			2.3			5			2.8		
Wald χ^2		48,076			11,133			11,441			16,541		
Prob > χ^2		0.000			0.000			0.000			0.000		
Log likelihood		4,118			1,891			1,779			2,609		
ln(Dairy Output)		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
ln(Fertiliser)		0.025	(0.004)	***	0.047	(0.008)	***	0.082	(0.017)	***	0.059	(0.008)	***
ln(Purchased Feed)		0.119	(0.014)	***	0.205	(0.012)	***	0.144	(0.011)	***	0.253	(0.012)	***
ln(Forage Area)		0.004	(0.009)		0.018	(0.017)		-0.047	(0.025)	*	-0.017	(0.016)	
ln(Dairy Cows)		0.837	(0.027)	***	0.622	(0.023)	***	0.804	(0.032)	***	0.694	(0.032)	***
ln(Labour hrs)		0.041	(0.011)	***	0.094	(0.014)	***	0.023	(0.017)		0.043	(0.014)	***
ln(Machinery)		0.039	(0.004)	***	0.026	(0.006)	***	0.034	(0.007)	***	0.059	(0.008)	***
ln(Buildings)		0.015	(0.003)	***	0.022	(0.004)	***	0.037	(0.008)	***	0.006	(0.001)	***
Altitude Zone 2 (d)		-0.086	(0.009)	***	-0.076	(0.012)	***	-0.085	(0.041)	**	-0.060	(0.022)	***
Altitude Zone 3 (d)		-0.062	(0.012)	***	-0.164	(0.014)	***	NA			0.079	(0.034)	**
TREND		0.009	(0.001)	***	0.015	(0.002)	***	0.004	(0.001)	***	0.005	(0.001)	***
Constant		7.495	(0.113)	***	7.786	(0.104)	***	6.884	(0.148)	***	6.792	-	-
μ	ln(Grass ratio)	-0.014	(0.506)		-0.019	(0.003)	***	-0.031	(0.012)	***	-0.010	(0.002)	***
	ln(Specialisation)	-1.209	(0.298)	***	-0.732	(0.050)	***	-0.882	(0.241)	***	-0.662	(0.094)	
σ_u	ln(Grass ratio)	0.129	(0.061)	**	1.315	(0.422)	***	NA	NA		NA	NA	
	ln(Specialisation)	4.051	(2.547)		29.876	(6.193)	***	NA	NA		NA	NA	
σ_v	TREND	NA			0.293	(0.018)	***	NA	NA		0.332	(0.019)	***

Table 6.4 Results of zonal production model

		Atlantic Plains			Central Europe			Whole sample		
No. Observations		7,206			18,318			25,524		
No. Farms		1,916			5,210			7,126		
Avg. Duration (years)		3.8			3.5			3.6		
Wald chi2		18,254			82,604			72,922		
Prob > chi2		0.000			0.000			0.000		
Log likelihood		4,710			5,518			14,562		
ln(Dairy Output)		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
ln(Fertiliser)		0.082	(0.011)	***	0.028	(0.003)	***	0.024	(0.004)	***
ln(Purchased Feed)		0.205	(0.012)	***	0.158	(0.011)	***	0.157	(0.010)	***
ln(Forage Area)		-0.013	(0.015)		-0.032	(0.007)	***	-0.010	(0.008)	
ln(Dairy Cows)		0.730	(0.026)	***	0.794	(0.015)	***	0.787	(0.014)	***
ln(Labour hrs)		0.031	(0.013)	**	0.062	(0.007)	***	0.049	(0.008)	***
ln(Machinery)		0.044	(0.007)	***	0.040	(0.003)	***	0.062	(0.004)	***
ln(Buildings)		0.006	(0.001)	***	0.022	(0.002)	***	0.012	(0.001)	***
Altitude Zone 2 (d)		-0.048	(0.021)	**	-0.078	(0.007)	***	-0.037	(0.007)	***
Altitude Zone 3 (d)		0.347	(0.034)	***	-0.103	(0.010)	***	-0.075	(0.011)	***
TREND		0.009	(0.001)	***	0.009	(0.001)	***	0.007	(0.001)	***
Constant		6.596	(0.135)	***	8.363	(0.093)	***	7.044	(0.066)	***
μ	ln(Grass ratio)	-0.015	(0.004)	***	-0.007	(0.002)	***	-0.003	(0.002)	
	ln(Specialisation)	-0.689	(0.128)	***	-0.435	(0.026)	***	-0.707	(0.061)	***
σ_u	ln(Grass ratio)	NA	NA		4.414	(0.973)	***	-0.519	(0.225)	**
	ln(Specialisation)	NA	NA		-3.061	(0.702)	***	21.495	(2.837)	***
σ_v	TREND	0.559	(0.034)	***	NA	NA		0.491	(0.012)	***

Cost models: drivers of CE

Tables 6.5 and 6.6 summarises the parameters of the cost frontiers and the inefficiency-effects models Again, most of the arguments to the cost function were statistically significant and were pointing in the expected positive direction, thus indicating that output levels and input prices were associated with higher cost. Exceptions to this were the price of cattle variable in both the French and the Atlantic Plains models, but neither of these parameters were statistically significant. The time trend’s parameter was negative in all models barring the German frontier, but again it failed to achieve statistical significance. This was expected. It indicated that the cost frontier was moving downward over time as production technology improved, and it agrees with the production models which indicates an exogenous increase in output over time, i.e. the production frontier shifts outward and the cost frontier shifts inward.

The p-values associated with the χ^2 statistic confirmed the joint significance of the model for each country. Furthermore the p-values for the arguments of the cost frontier indicated that variation in prices and output explained a statistically significant proportion of variation in expenditure in the frontier function.

Output level has the strongest effect on expenditure in all frontiers, as would be expected. The feed price had a stronger effect than fertiliser, which in turn had a stronger effect than the price of cattle except in Germany where the price of cattle has a slightly larger parameter than fertiliser. The relative importance of the other two prices over the cattle prices is understandable given that only about a fifth of dairy calves are generally required for herd replacement, so there is usually some scope to avoid detrimental price movements here.

Table 6.5 Results of the country-specific cost models

		Germany			France			Ireland			Wales		
No. Observations		14,887			4,609			3,639			5,595		
No. Farms		3,157			1,935			735			1,877		
Avg. Duration (years)		4.7			2.4			5.0			3.0		
Wald χ^2		9,430			4,579			5,936			11,022		
Prob > χ^2		0.000			0.000			0.000			0.000		
Log likelihood		2,862			-348			137			-307		
ln(Expenditure)		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
ln(Output)		1.051	(0.011)	***	1.037	(0.016)	***	0.973	(0.014)	***	0.982	(0.010)	***
ln(Cattle Price)		0.180	(0.052)	***	-0.128	(0.105)		0.314	(0.073)	***	0.343	(0.075)	***
ln(Feed Price)		0.356	(0.055)	***	1.171	(0.152)	***	0.909	(0.092)	***	1.008	(0.107)	***
ln(Fertiliser Price)		0.134	(0.055)	**	0.826	(0.126)	***	0.404	(0.085)	***	0.559	(0.090)	***
TREND		0.005	(0.003)		-0.054	(0.006)	***	-0.044	(0.005)	***	-0.049	(0.006)	***
Constant		-5.238	(0.362)	***	-70.387	(0.685)	***	-13.408	(0.523)	***	14.559	NA	
μ	ln(Grass ratio)	0.029	(0.003)	***	-0.004	(0.004)		-0.018	(0.006)	***	0.012	(0.003)	***
Feed ratio	ln(Specialisation)	-0.716	(0.092)	***	-0.797	(0.067)	***	-0.884	(0.082)	***	-0.884	(0.059)	***
σ_u	ln(Grass ratio)	NA	NA		0.961	NA		4.793	(1.334)	***	17.485	(2.245)	***
	ln(Specialisation)	NA	NA		191.425	(0.041)	***	-12.689	NA		-3.150	NA	
σ_v	TREND	0.747	(0.022)	***	0.320	(0.017)	***	NA	NA		NA	NA	

Table 6.6 Results of the zonal cost models

		Atlantic Plains			Central Europe			Whole sample		
No. Observations		7,899			20,831			28,730		
No. Farms		2,031			5,673			7,704		
Avg. Duration (years)		3.9			3.7			3.7		
Wald chi2		12,692			33,009			30,675		
Prob > chi2		0.000			0.000			0.000		
Log likelihood		2,228			-4,841			3,265		
ln(Expenditure)		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
ln(Output)		0.995	(0.009)	***	1.049	(0.006)	***	1.027	(0.006)	***
ln(Cattle Price)		-0.071	(0.066)		0.011	(0.043)		0.091	(0.038)	**
ln(Feed Price)		0.784	(0.163)	***	0.715	(0.029)	***	0.952	(0.084)	***
ln(Fertiliser Price)		0.556	(0.082)	***	0.600	(0.049)	***	0.248	(0.051)	***
TREND		-0.053	(0.004)	**	-0.023	(0.002)	***	-0.023	(0.002)	***
Constant		-9.209	(0.601)	***	15.217	(0.187)	***	-8.463	(0.331)	***
μ	ln(Grass ratio)	-0.018	(0.004)	***	0.018	(0.002)	***	0.010	(0.002)	***
	ln(Specialisation)	-1.006	(0.053)	***	-0.821	(0.036)	***	-0.844	(0.043)	***
σ_u	ln(Grass ratio)	0.487	NA		2.128	(0.339)	***	-0.769	(0.489)	
	ln(Specialisation)	13.592	2.917	***	6.281	(1.426)	***	3.503	(0.934)	***
σ_v	TREND	0.561	(0.021)	***	NA	NA		0.574	(0.013)	***

The inefficiency effects models give the drivers of cost efficiency for the cost models. Negative signs on the grass ratio variable appear in the French, Irish, and the Atlantic Plains models, although the variable is not statistically significant in the French model. The effect in Germany and Wales points in the opposite direction, as it does in the Central European zone and for the sample overall. This indicates increasing grass utilisation disimproves average cost efficiency outside of France, Ireland, and the Atlantic Plains, thus underscoring the importance of agronomic and structural differences when selecting the appropriate sample for constructing the frontier.

Given the apparent technical efficiency improving effect in the production models above, the change in the grass ratio's inefficiency effect is due entirely to the influence of input prices. It also gives a rationale as to why farms in these areas do not generally emphasize higher grass utilisation.

Finally, where the variance of v and u could be modeled, and where the effects were statistically significant, the parameter estimates were in agreement with the production models. The grass ratio and the specialisation ratio tended to increase the variability in u, and v tended to become more variable over time.

6.7 Conclusions

This section discusses the implications of the modelling carried out above. First, the author acknowledges the assumptions necessary to carry out the analysis, and also the limitations inherent in it. The paper concludes by tying results to policy.

Assumptions and limitations

As noted above, the Battese and Coelli model assumes time invariance in the inefficiency term, so the estimates will exhibit bias depending on the extent which this assumption does or does not hold in practice. Indeed, modelling the variance of the error components reveals that they are heteroscedastic in this application. Bias in the frontier and in the mean of u will have been reduced by this heteroscedasiic specification, and White's robust standard errors were also employed.

The use of national price indices omits any subnational price variation which may exist within any particular year. This variation in prices may be important to efficiency estimates if, for example, the timing of purchases consistently results in lower effective prices on certain farms relative to others, i.e. if this was a strategy by which farms pursued cost efficiency.

A Cobb-Douglas functional form is first order flexible whereas the translog functional form is second order flexible. The latter is usually preferred owing to this additional flexibility, but a Cobb-Douglas functional form was specified to ease estimation and interpretation of the results.

A truncated-normal distribution was assumed for the inefficiency term of the model. The reader should note that the efficiency estimates can display sensitivity to the choice of distribution, but the fact that the ranking of farms is less sensitive to this assumption should also be noted. The distributional assumption was tolerable, since this analysis was primarily concerned with the estimates of the drivers of efficiency, and not the actual levels of efficiency.

The biggest limitations to the analysis were data driven. There were a wide variety of grassland management practices which could be employed to potentially improve efficiency, but it was not possible to test most of these given the data available. This being the case, the research considered the simple hypothesis that higher levels of grass utilisation were associated with more efficient production in the dairy enterprise. However the best measure of grass utilisation available in the data was a ratio of Home-grown feed to all feed for purchased livestock. Home-grown feeds may come from several input categories besides grass, notably arable crops (e.g. maize silage), so this measure was better at distinguishing between grass-based versus concentrate feed systems than it was for comparisons to arable-based feed systems.

Implications of modelling exercise

The results from the models show structural factors in the MS led to differing implications for the efficiency of grass feed as measured by the constructed grass ratio. All countries in the sample show a efficiency-improving effect from the grass ratio, but when moving from technical efficiency to cost efficiency, i.e. an indication of economic efficiency, this was reduced to just two of the four countries, and only one of the two bio-economic zones. Given that the areas in which grass was cost efficiency-improving were also the areas which are known to utilise grass to a greater degree, the results support the hypothesis that system set up reflects the local price environment.

There was a higher degree of confidence that the proxy for grass utilisation performed well in Ireland and Wales where production systems were mainly grass based and where the proportion of grass in the Home-grown feed variable was expected to follow grass utilisation closely. There was less confidence in the measure’s performance in the

French and German data, as dairy systems there were more mixed and were more reliant on arable crops, e.g. maize silage.

However, summary statistics of the grass ratio and model results are generally in line with technical knowledge of production in each of the regions, so the proxy variable seems to have performed well. Even with the rough measure of grass utilisation constructed here, it was possible to detect a relationship between grass utilisation and efficiency, and the results agreed with analysis from Donnellan et.al. (2011) whereby grass forms an integral part of Irish cost competitiveness.

Nehring et al. (2009) researched the competitiveness of small farms in the U.S.A. using panel data ranging from 2003 to 2007. They also used a SFA model to compare the performance over time of conventional and pasture technologies which they identified using a binomial logit model. They too found that large conventional farms won out in most economic measures

Regarding efficiency disimproving effect for grass-utilisation in the Continental Europe zone, this result agrees with a U.S. based study done by Gillespie et al. (2009). They found that profitability was greater on intensive farming systems than on semi-pasture based systems, although they could not establish an effect for purely pasture based systems.

Although not examined here, some of the literature suggests that other regions of the EU may also find some CE improving effects from forage products. A study of Italian dairy farms done by Maietta (2000) suggests that. most of the allocative inefficiency present in that panel was due to under-utilisation of forage crops, although as stated earlier forage crops outside of the Atlantic plains region are more heavily weighted towards arable crops instead of grass.

The results suggest that research and development into effective grass management has been successful in improving cost efficiency, and further work in this area may also prove valuable to the Irish dairy sector in coming years. Similar inferences may be drawn for the Brittany and Normandy regions of France, but caution must be taken to account for structural differences before one may extrapolate such a policy conclusion to the Atlantic Plains region as a whole.

With this caution duly noted, a further conclusion concerns the targeting of policy. As the results vary widely depending on the grouping of farms, it is important to understand the interaction of the biological systems defined by the bio-geographical boundaries and the political systems defined by country boundaries. Policies which are based on membership in bio-geographical zones will be better targeted than national initiatives when it comes to agronomically appropriate dairy expansion strategies.

From an EU wide perspective, and given GHG reduction target for the EU generally, expansion in the Atlantic plains zone will likely be less damaging than similar expansions outside of this zone due to the cost advantage of grass input in the former. Therefore policies which encourage expansion in this zone and which favour grass input will allow expansion in the least GHG intensive manner, *ceteris paribus*.

Chapter 7 Concluding Chapter

7.1 Introduction

This thesis has presented analyses of the effects of milk quota on productivity, efficiency, and the distribution of farm income. The reader has also been provided with detailed reviews of the relevant policy environment, structural developments, and data sources which have informed these analyses. However, it remains to examine the connections between the various approaches, and to tease out the common themes of the results. This chapter will accomplish these tasks whilst also providing policy recommendations and suggestions for future research.

The remainder of the chapter is organised as follows: section 7.2 provides summaries of the analytical chapters main results. Section 7.3 discusses the implications of these results in relation to policy and future development of the dairy sector, and section 7.4 points out interesting areas for future work.

7.2 Chapter summaries

In light of the historical trends reported in Chapter 2, some effort was expended in constructing and analysing a long series of dairy enterprise TFP. Chapter 4 details that work. Newman and Matthews (2007) had previously established that specialist dairy producers operate under a fundamentally different technology than non-specialists; the work presented here therefore focused on specialist dairy producers only. Unlike other works, this research generated productivity measures at the dairy enterprise level.

Therefore, the generated series are more indicative of developments in milk production on Specialist Dairy farms than previous studies which take a whole-farm view. Movements in the overall index of TFP generally comport with the theory surrounding productivity and milk quota, as do movements in TFP's sub-components. An unexpected result was found in that scale efficiency change did not register any major disimprovment, and it has become an important determinant of overall TFP over time. The prime determinant of movements in TFP was found to be the technical change component, i.e. movements of the entire frontier. This was in harmony with findings from other works which address agriculture productivity in this part of the world.

Chapter 5 attempted to construct a counterfactual with respect to the distribution of farm income, and concluded that the "head start" on quota trade—indeed the effective removal of the binding constraint from a Northern Irish perspective—has not yielded a more advantageous result in terms of either average income or income equality amongst dairy farms. Furthermore, the analysis found some evidence that the introduction of tradable quota in Ireland improved farm incomes across the entire distribution of farms when looked at from a cash cost perspective, although contradictory results were found when total economic costs were considered. Lastly, regional analysis supported previous findings that removal of quota will tend to benefit the south-eastern region of Ireland, whilst the BMW will likely see a worsened financial situation.

Chapter 6 examined the impact of increased grass utilisation in the input mix of specialist dairy farms from a selection of 4 EU member states. That analysis found an efficiency-improving effect with respect to cost from small increases in grass input, but the effect was not uniformly applicable to all of the EU regions examined. Therefore, it also underscored the need to choose an appropriate sample depending on the nature of the research question, and—crucially—the technical knowledge of the differing technologies available in each MS. For example, there were far more agronomic similarities in groups of regions chosen by weather and soil criteria than if samples were chosen solely on the basis of national boundaries.

7.3 Discussion

Throughout this thesis, the reader has been exposed to data and analyses which were surrounded by the common themes of structural change, output expansion, productivity, and efficiency as they pertain to the dairy sector in Ireland and in a selection of other Western European countries. The results suggest a few broad conclusions.

For a start, the analysis of TFP and its subcomponents shows that the evolution of productivity continues on a largely positive trend within Ireland, but growth is and has been very weak. The growth that has occurred has been driven mainly by movements in the production frontier. Productivity growth rates weakened substantially when comparing the years before quotas were instituted to the years immediately afterward. However, technical efficiency was only mildly affected, and indeed that component of TFP hasn’t contributed significantly to the overall movement of the TFP index at any point over the lifetime of the policy. This underscores the notion that competitiveness relies on not only technical efficiency, but also on the adoption of innovative technical developments, i.e. technical change (Valergakis, 2007).

The indices also fail to register any adverse effects for scale efficiency change; this element continues to grow at a slow but increasing pace which gives no indication of being phased by milk quotas at all. This result may reflect an inability of the model to adequately identify scale efficiency change, perhaps placing those effects in the technical change component instead. Furthermore, there is no counterfactual against which one may compare this series, and perhaps scale change would have proceeded at a much faster pace in the absence of milk quota. However, if the scale efficiency change result is accurate, then inefficient scale has neither been the result of—nor exacerbated by—milk quota policy. Surprising as this may seem, there are many other reasons for the anaemic land market in this country (McDonald et al. 2014, p.23). These forces predated milk quota, and in all likelihood will persist beyond abolition of the policy. Despite the fact that the growth rate of scale efficiency change grew over time, this growth is still weak. Given its increased importance in overall productivity, further policies to encourage scale change, i.e. cooperative use or concentration of land resources, may still be needed.

The inter-country comparisons carried out in this thesis shed more light on quota policy's interaction with system choice and financial outcomes for dairy farms. In modelling production and cost frontiers for a selection of EU member states, it is shown that grass utilisation has a disimproving effect on TE, but in certain circumstances an improving effect on CE. In regions where grass growth is favourable, using this resource effectively conveys a comparative advantage that has been exploited during the milk quota era. Policies which encourage efficient grassland use will help mitigate some of the negative externalities which can arise from a dairy expansion, particularly in light of the fact that no price for carbon exists for agriculture as of yet and that some analysis associates low carbon prices with soil and livestock mitigation measures (Schneider and McCarl, 2002).

The comparative study of Ireland and Northern Ireland provides a window to a counterfactual world in which quota was not a consideration for Irish dairy production.

Care must be taken in this comparison, as there are non-trivial structural differences which must be considered even in so small a geographic space. However, the results suggest that in the absence of the quota constraint, a certain emphasis is placed on expansion, and the worry is that this occurs to the detriment of efficiency. Northern Irish dairy farms have increasingly fuelled output gains with progressively larger proportions of supplemental feed. Northern Irish farms are therefore more exposed to feed price risk, and less exposed to weather and fertiliser price risks. When scaled to per hectare or per labour unit measures, Northern Irish farms have generally been at an income disadvantage as compared to their counterparts in the State. This too points towards a need for policies which encourage efficient grassland use, and here it supports economically viable expansion on smaller farms. Groot et al. (2006) found that continuous gradual adjustment of integrated farm management combined with varying strategies regarding productivity improvement performed best with respect to adaptation to policy changes amongst their sample of farms in the Netherlands, and this suggests that policies which encourage a more incremental expansion path may be best.

In their totality, the separate analyses suggest that milk quota has been effective in supporting the continued existence of smaller farms alongside its primary goal of limiting the EU budget exposure to excessive dairy production. Market share was spread across more farms than would have been otherwise, and combining this with the possibility to sell one’s quota meant that there were multiple routes to respectable income on a large number of farms. Quota’s absence will remove some of these routes, and make it more difficult for smaller dairy farms to continue in production, whilst at the same time allowing other farms an opportunity to expand where circumstances are favourable.

When viewed in this way, milk quota becomes not only a supply control measure, but also an instrument of redistribution, and the question of whether or not such a policy should exist becomes a normative value judgement. That discussion is beyond the scope of this work, but if society has a preference for the current distribution of farm income amongst the population of dairy farms, then another means of supporting smaller dairy farms will likely be required in the future.

It is necessary to point out that the results contained herein suggest that the notion of a cost of milk quota in terms of efficiency only makes sense from a sectoral point of view. Although quota disimproved sector wide productivity, this did not destroy the average efficiency of dairy farms, i.e. most farms have been quite close to the productive frontier, even as it has moved over time. This is entirely due to the relativistic nature of the measures of efficiency one obtains from SFA models, i.e. they record the dispersion of input-output bundles, and not the absolute level of such bundles as in Farrell's description of the engineer's approach to efficiency measurement.

An instructive way to think about this point goes as follows; if society chooses this level of sectoral output, then the number of farms is too large to be efficient because more concentration and intensification of production needs to occur. However, if society chooses this distribution of farms and level of income equality, then output is produced at a reasonably efficient point.

To the extent that milk quotas have provided an impetus to reduce herd sizes, the policy will have been associated with lower GHG emissions in absolute terms, however some authors have found that environmental efficiency per unit of output may actually increase with intensity of production (Reinhard et al., 1999).

If the overall level of quota represents society's preference for a reduced level of some of the negative externalities associated with dairy production, or if there is a social preference for the spatial or income distribution of dairy farms, then quota should be viewed in the same way as any tradable permit for a polluting good per the Coase Theorem (Coase 1960). Society will have paid the cost of reduced productive efficiency (relative to an unconstrained industry) to obtain an outcome which is Pareto-efficient in the welfare theoretic sense.

7.4 Future research

The Irish dairy sector provides an historical example of consistently high level of technical and cost efficiency at the farm level. The years of production constraints in the form of milk quotas have not stopped this from being the case, but some questions remain.

Determining the most appropriate way to construct that counterfactual may well prove a fruitful area for future research of milk quotas. The natural experiment presented in Chapter 5 attempts to control for structural differences through separate comparisons of regions, but techniques such as propensity score matching, difference-in-difference models, and regression discontinuity models may provide a way to estimate parametric models, inclusive of SFA models. The major benefit here would be a sense of the magnitude of the effects of milk quota policy, which is lacking in the directional analysis undertaken in this thesis.

Further to this point, Chapter 6 underscored the importance of the researcher's decision to elect a sample for inclusion under a common frontier. The question of a rigourous and standardised technique for the selection of appropriate samples is missing from the productivity literature. This must surely be an area worthy of attention, given the sensitivity to the relative homogeneity of samples exhibited by the most common techniques in productivity analysis.

There is still a great need for an understanding of the environmental costs of dairy production, and this only intensifies with the possibility of dairy expansion. Several approaches are possible, e.g. van de Ven and van Keulen, (2007) for mathematical programming of multi-goal optimisation, and for a partial equilibrium analysis Donnellan, Gillespie and Hanrahan (2009) provides an example. The latter study implies a very large contraction of bovine populations in Ireland is necessary to hit a hypothesised proportional mitigation target under the EU 20-20-20 agreement, but it is important to note that this result depends on the GHG accounting approach taken (Casey and Holden, 2005).

The productivity and efficiency literature is moving towards more inclusive SFA and DEA models as well, e.g. environmental efficiency (Coelli, Lauwers, and Van Huylenbroek, 2007; Nevens et al. 2006; Reinhard et al., 1999). Given the grass-based nature of production in Ireland and several other regions in the Atlantic Plains zone of the EU, this seems a very natural extension of the work carried out in Chapter 6.

The potential benefits of milk quota may not have been restricted to the reduction of negative externalities. Though sectoral productivity growth rates may have suffered from milk quotas, this research is suggestive that it may have resulted in ‘better’ farm practices inasmuch as grass management has been given considerable attention in Ireland. Rewards from these research efforts will continue to accrue to individual farms—private firms—even as the sector now heads into a new expansionary period. This would be in keeping with the Porter Hypothesis (Porter and van der Linde 1995), whereby the increased cost imposed on dairy producers by milk quotas incentivised innovation, and in turn created a long-run payoff in terms of dynamic efficiency. Tradable permit systems such as milk quotas have been shown to have this sort of effect before (Kerr and Newell 2003). To ascertain whether or not this has been the experience of Ireland under milk quotas—as the current work suggests—is a logical next step for future research.

Chapter A Appendix

A.1 Regularity conditions for the grass efficiency study

Well behaved production and cost frontiers must meet the usual regularity conditions ascribed to them by neoclassical theory. A necessary and sufficient condition for the convexity of a production frontier was that its Hessian matrix was negative semi-definite. This can be checked by visual inspection of the main diagonal of the frontier's Hessian.

The open-source software Maxima was used to calculate and evaluate the Hessian matrix at the mean for each of the frontiers' inputs. These were listed below. The functional form chosen for these frontiers was the Cobb-Douglas function which was self-dual, and which globally satisfies the curvature conditions automatically as long as the monotonicity conditions have been upheld. The main diagonal of these matrices are the second derivative of the function with respect to a each input, and the law of diminishing returns dictates that these should be negative.

The matrices listed below show violations of monotonicity, and hence also the convexity assumption, for all the estimated frontiers. However, it was also apparent that these violations were the results of monotonicity violations of one (forage area) or two inputs.

Table A.1 German production frontier Hessian matrix

$$\begin{bmatrix}
-4.96\ 10^{-7} & 1.249\ 10^{-8} & -1.945\ 10^{-6} & 3.812\ 10^{-5} & 2.635\ 10^{-8} & 1.134\ 10^{-9} & 2.905\ 10^{-10} \\
1.249\ 10^{-8} & -8.012\ 10^{-8} & -2.081\ 10^{-6} & 4.079\ 10^{-5} & 2.819\ 10^{-8} & 1.213\ 10^{-9} & 3.109\ 10^{-10} \\
-1.945\ 10^{-6} & -2.081\ 10^{-6} & 0.01441 & -0.006351 & -4.39\ 10^{-6} & -1.889\ 10^{-7} & -4.84\ 10^{-8} \\
3.812\ 10^{-5} & 4.079\ 10^{-5} & -0.006351 & -0.0237 & 8.603\ 10^{-5} & 3.703\ 10^{-6} & 9.485\ 10^{-7} \\
2.635\ 10^{-8} & 2.819\ 10^{-8} & -4.39\ 10^{-6} & 8.603\ 10^{-5} & -1.084\ 10^{-6} & 2.559\ 10^{-9} & 6.556\ 10^{-10} \\
1.134\ 10^{-9} & 1.213\ 10^{-9} & -1.889\ 10^{-7} & 3.703\ 10^{-6} & 2.559\ 10^{-9} & -2.577\ 10^{-9} & 2.822\ 10^{-11} \\
2.905\ 10^{-10} & 3.109\ 10^{-10} & -4.84\ 10^{-8} & 9.485\ 10^{-7} & 6.556\ 10^{-10} & 2.822\ 10^{-11} & -5.488\ 10^{-10}
\end{bmatrix}$$

Table A.2 French production frontier Hessian matrix

$$\begin{bmatrix}
-3.522\ 10^{-7} & 1.998\ 10^{-8} & -5.09\ 10^{-6} & 3.478\ 10^{-5} & 7.01\ 10^{-8} & 1.03\ 10^{-9} & 6.656\ 10^{-10} \\
1.998\ 10^{-8} & -1.576\ 10^{-7} & -8.461\ 10^{-6} & 5.781\ 10^{-5} & 1.165\ 10^{-7} & 1.712\ 10^{-9} & 1.106\ 10^{-9} \\
-5.09\ 10^{-6} & -8.461\ 10^{-6} & 0.03015 & -0.01473 & -2.968\ 10^{-5} & -4.362\ 10^{-7} & -2.818\ 10^{-7} \\
3.478\ 10^{-5} & 5.781\ 10^{-5} & -0.01473 & -0.03933 & 2.028\ 10^{-4} & 2.98\ 10^{-6} & 1.925\ 10^{-6} \\
7.01\ 10^{-8} & 1.165\ 10^{-7} & -2.968\ 10^{-5} & 2.028\ 10^{-4} & -3.341\ 10^{-6} & 6.006\ 10^{-9} & 3.881\ 10^{-9} \\
1.03\ 10^{-9} & 1.712\ 10^{-9} & -4.362\ 10^{-7} & 2.98\ 10^{-6} & 6.006\ 10^{-9} & -3.306\ 10^{-9} & 5.703\ 10^{-11} \\
6.656\ 10^{-10} & 1.106\ 10^{-9} & -2.818\ 10^{-7} & 1.925\ 10^{-6} & 3.881\ 10^{-9} & 5.703\ 10^{-11} & -1.638\ 10^{-9}
\end{bmatrix}$$

Table A.3 Irish production frontier Hessian matrix

$$\begin{bmatrix}
-5.513\ 10^{-7} & 3.325\ 10^{-8} & -2.115\ 10^{-5} & 7.967\ 10^{-5} & 2.029\ 10^{-8} & 4.781\ 10^{-9} & 2.388\ 10^{-9} \\
3.325\ 10^{-8} & -1.607\ 10^{-7} & -1.776\ 10^{-5} & 6.691\ 10^{-5} & 1.704\ 10^{-8} & 4.016\ 10^{-9} & 2.006\ 10^{-9} \\
-2.115\ 10^{-5} & -1.776\ 10^{-5} & 0.09957 & -0.04256 & -1.084\ 10^{-5} & -2.554\ 10^{-6} & -1.276\ 10^{-6} \\
7.967\ 10^{-5} & 6.691\ 10^{-5} & -0.04256 & -0.01702 & 4.083\ 10^{-5} & 9.621\ 10^{-6} & 4.806\ 10^{-6} \\
2.029\ 10^{-8} & 1.704\ 10^{-8} & -1.084\ 10^{-5} & 4.083\ 10^{-5} & -5.37\ 10^{-7} & 2.45\ 10^{-9} & 1.224\ 10^{-9} \\
4.781\ 10^{-9} & 4.016\ 10^{-9} & -2.554\ 10^{-6} & 9.621\ 10^{-6} & 2.45\ 10^{-9} & -1.64\ 10^{-8} & 2.884\ 10^{-10} \\
2.388\ 10^{-9} & 2.006\ 10^{-9} & -1.276\ 10^{-6} & 4.806\ 10^{-6} & 1.224\ 10^{-9} & 2.884\ 10^{-10} & -3.75\ 10^{-9}
\end{bmatrix}$$

Table A.4 Welsh production frontier Hessian matrix

$$\begin{bmatrix} -2.971\ 10^{-7} & 1.264\ 10^{-8} & -6.443\ 10^{-6} & 2.693\ 10^{-5} & -2.094\ 10^{-9} & 2.347\ 10^{-9} & 2.326\ 10^{-10} \\ 1.264\ 10^{-8} & -6.47\ 10^{-8} & -1.069\ 10^{-5} & 4.472\ 10^{-5} & -3.476\ 10^{-9} & 3.897\ 10^{-9} & 3.862\ 10^{-10} \\ -6.443\ 10^{-6} & -1.069\ 10^{-5} & 0.05994 & -0.02278 & 1.771\ 10^{-6} & -1.985\ 10^{-6} & -1.967\ 10^{-7} \\ 2.693\ 10^{-5} & 4.472\ 10^{-5} & -0.02278 & -0.01628 & -7.405\ 10^{-6} & 8.302\ 10^{-6} & 8.228\ 10^{-7} \\ -2.094\ 10^{-9} & -3.476\ 10^{-9} & 1.771\ 10^{-6} & -7.405\ 10^{-6} & 1.445\ 10^{-7} & -6.454\ 10^{-10} & -6.396\ 10^{-11} \\ 2.347\ 10^{-9} & 3.897\ 10^{-9} & -1.985\ 10^{-6} & 8.302\ 10^{-6} & -6.454\ 10^{-10} & -1.153\ 10^{-8} & 7.17\ 10^{-11} \\ 2.326\ 10^{-10} & 3.862\ 10^{-10} & -1.967\ 10^{-7} & 8.228\ 10^{-7} & -6.396\ 10^{-11} & 7.17\ 10^{-11} & -2.361\ 10^{-9} \end{bmatrix}$$

Table A.5 Atlantic plains production frontier Hessian matrix

$$\begin{bmatrix} -1.283\ 10^{-7} & 6.733\ 10^{-9} & -2.926\ 10^{-6} & 1.617\ 10^{-5} & -4.481\ 10^{-9} & 1.614\ 10^{-9} & 0 \\ 6.733\ 10^{-9} & -7.648\ 10^{-8} & -6.52\ 10^{-6} & 3.603\ 10^{-5} & -9.985\ 10^{-9} & 3.598\ 10^{-9} & 0 \\ -2.926\ 10^{-6} & -6.52\ 10^{-6} & 0.03467 & -0.01566 & 4.339\ 10^{-6} & -1.563\ 10^{-6} & 0 \\ 1.617\ 10^{-5} & 3.603\ 10^{-5} & -0.01566 & -0.009725 & -2.398\ 10^{-5} & 8.643\ 10^{-6} & 0 \\ -4.481\ 10^{-9} & -9.985\ 10^{-9} & 4.339\ 10^{-6} & -2.398\ 10^{-5} & 3.758\ 10^{-7} & -2.394\ 10^{-9} & 0 \\ 1.614\ 10^{-9} & 3.598\ 10^{-9} & -1.563\ 10^{-6} & 8.643\ 10^{-6} & -2.394\ 10^{-9} & -1.164\ 10^{-8} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Table A.6 Continental Europe production frontier Hessian matrix

$$\begin{bmatrix} -3.471\ 10^{-7} & 9.244\ 10^{-9} & -3.09\ 10^{-6} & 2.9\ 10^{-5} & 2.585\ 10^{-8} & 1.034\ 10^{-9} & 4.656\ 10^{-10} \\ 9.244\ 10^{-9} & -7.375\ 10^{-8} & -4.248\ 10^{-6} & 3.987\ 10^{-5} & 3.554\ 10^{-8} & 1.421\ 10^{-9} & 6.402\ 10^{-10} \\ -3.09\ 10^{-6} & -4.248\ 10^{-6} & 0.02926 & -0.01333 & -1.188\ 10^{-5} & -4.752\ 10^{-7} & -2.14\ 10^{-7} \\ 2.9\ 10^{-5} & 3.987\ 10^{-5} & -0.01333 & -0.0219 & 1.115\ 10^{-4} & 4.461\ 10^{-6} & 2.008\ 10^{-6} \\ 2.585\ 10^{-8} & 3.554\ 10^{-8} & -1.188\ 10^{-5} & 1.115\ 10^{-4} & -1.53\ 10^{-6} & 3.976\ 10^{-9} & 1.79\ 10^{-9} \\ 1.034\ 10^{-9} & 1.421\ 10^{-9} & -4.752\ 10^{-7} & 4.461\ 10^{-6} & 3.976\ 10^{-9} & -3.627\ 10^{-9} & 7.162\ 10^{-11} \\ 4.656\ 10^{-10} & 6.402\ 10^{-10} & -2.14\ 10^{-7} & 2.008\ 10^{-6} & 1.79\ 10^{-9} & 7.162\ 10^{-11} & -1.503\ 10^{-9} \end{bmatrix}$$

A.2 Regularity conditions for Irish TFP study

Chapter 4 uses a translog functional form to estimate the production frontier. This is more realistic, but checking that the estimated models are consistent with microeconomic theory.is more complicated. The details of the tests are given below.

Table A.7 Specification tests of dairy enterprise production technology

H_0 Cobb-Douglas production function
H_A Translog production function
Statistic: 165.40
Critical Value: $\chi_{15,0.01} = 30.58$
Reject null at 1% significance

H_0 Translog, no technical change
H_A Translog, neutral technical change
Statistic: 1116.00
Critical Value: $\chi_{33,0.01} = 54.78$
Reject null at 1% significance

H_0 Translog, neutral technical change, no sampling controls
H_A Translog, neutral technical change, with sampling controls
Statistic: 18.35
Critical Value: $\chi_{5,0.01} = 15.09$
Reject null at 1% significance

Hausman test for RE vs. FE (estimates from OLS panel regression used)
H_0 Farm effect is uncorrelated with error term (RE is favoured)
H_A Farm effect is correlated with error term (FE is favoured)
Statistic: 685.81
p-value: $p_{57,0.05} = 0.00$
Reject null at 5% significance

Table A.7 above details the likelihood-ratio tests used to determine the appropriateness of the included variables. The tests start from the core specification using a Cobb-Douglas functional form only. The Cobb-Douglas is nested inside of the translog functional form, so adding in the quadratic terms to the Cobb-Douglas allows a test statistic which follows a χ^2 distribution with 15 degrees of freedom (parameter restrictions). The test is statistically significant at a 99 per cent confidence level, and this supports the use of a translog functional form.

The next test in the table examines the joint significance of the 33 time-dummy variables which were specified in the model to represent Hick's neutral technical change. The test is statistically significant with 33 degrees of freedom at the 99 per cent confidence level, so the test supports the existence of technical change in the model.

The third test verifies the need for the control variables which were specified to remove the effects of changes in the sampling methodology from the other parameter estimates. The controls are dummy variables which indicate the size strata the farms belong to and these are interacted with a dummy variable indicating the first five years of the sample. The test has five degrees of freedom and is statistically significant at the 99 per cent confidence level. This supports the inclusion of the sampling controls in the model.

The fourth test on the table is not a likelihood ratio test, but the standard Hausman test to determine whether fixed effects (FE) or a random effects (RE) type of panel model is more appropriate. The RE model is more efficient, but its parameters will be biased if the Hausman rejects the null hypothesis of no correlation between the individual effect and the model's error term. The Hausman test is an $\mathcal{F}$ test. In this case, there are 57 degrees of freedom, and the null hypothesis is rejected at the 95 per cent confidence level. This suggests the use of a FE type of model, but the test is meant to be applied for a typical OLS panel model. Indeed, the test was carried out on an OLS version of the same specification here. The link between this test and the choice between the TFE and TRE versions of the SFA family of models is not clear. The test is included in the table for completeness, but theoretical tests below strongly support the use of the TRE model instead.

The assessment of theoretical consistency involves evaluating the modeled production function using the estimated parameters, and in the case of the translog functional form, also the individual values of each variable in the model. The first order (monotonicity) condition for the translog production function is

$$\frac{\partial y}{\partial x_i} = \left(\frac{y}{x_i}\right) * \left(a_i + \sum_{j=1}^{n} a_{ij} \ln x_j\right) > 0 \qquad \text{(A.1)}$$

The second order condition requires the second derivatives with respect to each input of the model to be strictly negative. The inequality can be written for the translog as

$$\frac{\partial^2 y}{\partial x_i^2} = \left[a_{ii} + \left(a_i - 1 + \sum_{j=1}^{n} a_{ij} \ln x_j\right) * \left(a_i + \sum_{j=1}^{n} a_{ij} \ln x_j\right)\right] * \left(\frac{y}{x_i^2}\right) < 0 \qquad \text{(A.2)}$$

It can be seen from (A.1) and (A.2) that these two conditions depend on model parameters, as well as depending on the data points themselves, so it is incumbent on the researcher to check the extent to which any individual dataset violates theory. If each data point is thought of as a row in a spreadsheet, then checking these assumptions can be thought of as calculating the values of (A.1) and (A.2) for each input, one row at a time. In the five-input model estimated here, this results in 10 new variables, i.e. a first and second derivative with respect to each input, calculated for each farm-year. Once these variables exist in the data, a dummy variable may be conditioned to take a value of one, e.g. if all the first derivatives are positive. The mean of such a binary variable can be interpreted as the proportion of the sample which satisfies the condition. Table A.8 below summarizes the results of this procedure when applied to this particular specification. The table reveals that more standard Pitt-Lee and Battese-Coelli variants of the SF model generally outperform the more recent ‘true effects’ models. In particular, the TFE model almost always violates theory for this model specification and dataset. So despite the possibility of some bias in an RE type of model as suggested by the Hausman test, the TFE’s inconsistency strongly dissuades the researcher from implementing it over the TRE model. Furthermore, Table A.9 shows that there is a high correlation between the inefficiency parameter estimates from the TRE and TFE model, suggesting that while some bias may exist in the parameter estimates from the TRE version, the severity of this bias may not be too great.

Table A.8 Percentages of sample meeting theoretical regularity conditions

	Monotonicity	Diminishing marginal product	Monotonicity & Diminishing Marginal Product
Pitt-Lee	84	96	84
Battese – Coelli	84	96	84
True Random Effects	76	86	76
True Fixed Effects	2	0	0

The regularity conditions are simplified at the point of approximation if the data have been transformed such that are equal to unity at that point. Researchers typically choose the means of the variables as the point of approximation, so the procedure is to simply divide each variable by its own mean. Recalling (A.1), one sees that the second term of the inequality involves $\ln x_i$, but since x_i has been transformed in this way, this will become the logarithm of unity, which is always equal to zero. Hence the second term simplifies to a_i, that is the main effect. This can now be directly interpreted as the elasticity, just as in the Cobb-Douglas form albeit only when evaluating the function *at this point*. In essence, the regularity conditions become functions of the parameters alone for this special case. This is convenient, and it facilitates the checking of the quasi-concavity condition.

Table A.9 Correlations amongst model estimates of inefficiency parameter

	PL	BC	TRE	TFE
PL	1.00	0.99	0.42	0.28
BC	0.99	1.00	0.43	0.28
TRE	0.42	0.43	1.00	0.90
TFE	0.28	0.28	0.90	1.00

Table A.10 below summarizes the results of the regularity checks. The TFE model does not fulfill any of the theoretical conditions, whereas the other three versions of the model meet the first and second order conditions, but also fail to satisfy the concavity condition.

Table A.10 Regularity conditions for translog production function (evaluated at sample means)

	Monotonicity	Diminishing marginal product	Quasi-concavity
Pitt-Lee	F	F	NF
Battese – Coelli	F	F	NF
True Random Effects	F	F	NF
True Fixed Effects	NF	NF	NF

F = condition fulfilled, NF = condition not fulfilled

Quasi-concavity evaluated on the basis of eigenvalues of the bordered Hessian matrix. Negative values for all eigenvalues indicate a negative semi-definite matrix, which is a necessary and sufficient condition for local concavity.

Table A**.11** gives the results of the test of the hypothesis that the technology exhibits constant returns to scale. The test is a Wald test which follows a χ^2 distribution. There are six degrees of freedom to the test; each restriction of the model adds a degree of freedom. The restrictions do two things; first the main effects are forced to sum to unity, and secondly each input's quadratic terms are forced to sum to zero. Failure to reject these restrictions lends supports the existence of constant returns to scale, whilst a rejection supports variable returns to scale. The table shows that the null hypothesis of CRS is clearly rejected for all variants of the SF model.

The Pitt-Lee and Battese-Coelli models tend to be the most consistent with theory in this dataset and for this model, but these variants of the SF modeling framework are also more rigid in terms of their treatment of inefficiency. As discussed above, the Pitt-Lee model assumes that inefficiency is completely time invariant; the inefficiency component is determined in the first period and assumed the same for the rest of the time horizon. Over long panels this assumption becomes more restrictive, as it seems plausible that many farms may experience changes in their efficiency levels.

The Battese-Coelli model is a standard for efficiency analysis , and it does allow inefficiency to develop over time, but the path of this development is prescribed by the model to be identical for all farms'; they differ only in their starting points. This also seems restrictive in a 34 year long panel.

The 'true effects' models are far less restrictive in this regard, as they allow each farm's efficiency to follow its own development path over time. As noted above, the TFE model performs quite poorly in terms of theoretical consistency, so the TRE variant of the SF model is preferred for this analysis.

Table A.11 Hypothesis tests of constant returns to scale

	Wald Statistic $\chi^2_{6,0.05}$	p-value	Conclusion
Pitt-Lee	157.35	0.00	VRS
Battese – Coelli	154.67	0.00	VRS
True Random Effects	210.42	0.00	VRS
True Fixed Effects	147.03	0.00	VRS

CRS – constant returns to scale, VRS – variable returns to scale.

It is possible to impose CRS onto the data through parameter restrictions, but doing so does not improve theoretical consistency in this dataset, and the test results indicate that such restrictions may introduce more bias into the model, so those results are not shown.

Table 4.3 reports (weighted) mean input elasticities and technical efficiency scores resulting from the TRE version of the model for a selection of individual years. The function was generally increasing with inputs, as theory dictates. Slightly increasing returns to scale were consistently present, and in a few years there were negative signs on the labour and land inputs. This result has been observed before (Carroll et al, 2008) and may be indicative of some variability in soil quality (farms with poorer land also tend to be larger in physical terms).

Table A.12 Input elasticities and returns to scale (selected years)

	1979	1984	1990	1995	2000	2007	2012
TE	0.89	0.88	0.93	0.93	0.94	0.92	0.92
ϵ_1	0.87	0.8	0.79	0.75	0.73	0.71	0.65
ϵ_2	0.18	0.22	0.22	0.23	0.23	0.23	0.25
ϵ_3	0.06	0.06	0.06	0.06	0.06	0.06	0.05
ϵ_4	-0.02	0	0.01	0.02	0.03	0.06	0.09
ϵ_5	-0.02	0	0.01	0.02	0.02	0.01	0.01
RTS	1.08	1.08	1.08	1.08	1.07	1.07	1.06

TE = technical efficiency
RTS = returns to scale

Furthermore, Table A.13 shows that the model's input variables are correlated, although not so much as to prevent the model from estimating with statistically significant parameters

Table A.13 Correlations amongst input variables

	x_1	x_2	x_3	x_4	x_5
x_1	1.00	0.89	0.77	0.85	0.75
x_2	0.89	1.00	0.77	0.72	0.68
x_3	0.77	0.77	1.00	0.60	0.58
x_4	0.85	0.72	0.60	1.00	0.66
x_5	0.75	0.68	0.58	0.66	1

Multi-collinearity can result in some parameters having incorrect signs, so this may have contributed somewhat to the theoretical violations observed. The estimated returns to scale associated with this production function were 1.075 with a standard deviation of 0.007 over the 34 yearly observations.

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