REFEREED ARTICLE

An economic analysis of the Irish milk quota exchange scheme

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ABSTRACT

In Ireland, the trade of milk quota is subject to regional restrictions and a large variation in quota prices between regions has caused some controversy. This article investigates this issue by analysing the functioning of the Irish milk quota exchange market. For this purpose, the economic value of milk quota is estimated using an optimisation framework. The estimated values are then compared to milk quota prices paid at the exchange market. The analysis reveals that quota is undervalued in the border, midlands and west and south-west regions, while milk quota is overvalued in the east and south regions. This implies that farmers in certain regions overpay for additional quota, while other farmers secure good value for their quota investments. The paper concludes by discussing that the identified regional differences are only partly explained by economic and production factors.

KEYWORDS: Milk quota trade; optimisation modelling; dairy production

1. Introduction

It is well understood and supported by many economic studies that quotas introduce inefficiency in a sector but that this inefficiency can be reduced if the quota is traded freely between producers (e.g. Colman, 2000; Hennessy et al., 2009). Despite this, few Member States of the European Union (EU) permit open trade in milk quotas. Quota trade restrictions come in the form of regional restrictions, quota price cooling mechanisms, taxes on transfers and so forth (e.g. Bogetoft et al., 2003; Colman, 2000). These restrictions are mostly motivated by social goals but they have economic consequences that affect the efficiency of the dairy sector, the functioning of the quota market, the price at which quota is traded and ultimately farmers' welfare.

The EU dairy sector has been restricted by milk quotas since 1984 in order to limit public expenditure on the dairy sector, to control dairy production, and to stabilize milk prices and the incomes of dairy farmers (EC, 2009). The abolition of milk quotas in 2015 was first stipulated at the Luxembourg Agreement of the Mid Term Review of the Common Agricultural Policy (CAP) in 2003, and the abolition of milk quotas has been confirmed at the subsequent Health Check of the CAP (EC, 2009). In order to prepare the sector for the imminent removal of milk quotas, national milk quotas increase by 1% annually from 2009 to 2013.

The removal of milk quotas is expected to have large implications for the dairy sector, as for the first time in over 25 years, dairy farmers will be able to expand milk production without restrictions. However, still being subject to quota restrictions, dairy farmers face difficult decisions whether and when to expand milk production. Increasing milk production by acquiring additional quota on the milk quota market is a difficult decision for dairy farmers, since the economic consequences of this decision depend on the future profitability of dairy farming (Hanson, 2009).

In this analysis we study the Irish milk quota market. The exchange of milk quota in Ireland has been allowed since the beginning of 2007, but the ring-fencing of quota in general, and the large variation in milk quota prices in particular, has been the subject of considerable controversy in Ireland. Many theories have been postulated as to why the large variation in quota prices exist, however there has been no empirical analysis of this issue to date. On the one hand the economics of milk production in the various regions may justify the price differential; however there may also be an element of farmer behaviour or regional idiosyncrasies at play.

The objective of this paper is to investigate the functioning of the Irish milk quota trading scheme by comparing the estimated economic value of milk quota to actual trade prices observed at the milk quota trading scheme. The purpose of this analysis is to identify whether quota is over- or undervalued in certain regions. The results of this analysis are relevant to policy makers as they allow suggestions as to where milk production is likely to move after the abolition of quota. Further, the findings are also of relevance for farmers wishing to expand milk production. The results can serve as a decision tool whether to invest in quota or to wait until quotas are abolished.

Following the introduction, the Irish milk quota trading scheme is outlined. Next, the details of an empirical model that is developed to estimate the economic value of milk quota are presented. In section

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4 the data are described. The subsequent section presents the results, followed by some final conclusions.

2. Background

In Ireland, the transfer of quota between farmers has been permitted since the late 1980s but such transfers were highly regulated and mostly attached to land. In 2007, a new milk quota allocation scheme has been introduced allowing farmers to make permanent quota transfers separate from land. The quota allocation scheme can be divided into three schemes: the milk quota trading scheme, the temporary leasing scheme and the reallocation of unused quota. Since the milk quota trading scheme is the main scheme by which quota can be allocated to different producers, the focus of this study is on the milk quota trading scheme.

The milk quota trading scheme is operated on a biannual basis and takes place at the beginning and in autumn of each year. Each of the approximately 30 dairy processors (co-operatives) operates a ring-fenced quota exchange, i.e. quota cannot be moved from one exchange to another. Farmers give a single-bid, stating price and quantity that they are willing to sell or to buy. The equilibrium price at which quota is traded is subject to some intervention and market cooling mechanism. For example, 30% of the milk offered for sale is transferred to a priority pool sold at a fixed price to successors, new entrants or lost leases. This implies that the scheme consists of a priority pool and a market exchange. All offers to buy and to sell are entered into the exchange and the initial equilibrium price is calculated as follows: only 70% of the quantity offered will be considered for the equilibrium price calculation as 30% of the quantity offered goes directly into the priority pool. Next, all offers and demands are ordered on the price quoted. Offers are added up from the lowest price, while demands are added up the opposite way. The initial equilibrium price is either the price at which the quantity offered equals the quantity demanded or, if that price does not exist, the price with the least difference between the two quantities where demand exceeds supply (DAFF, 2011a). After the initial equilibrium price is calculated, all bids that exceed the calculated price by 40% or more will be removed and the price is calculated again without those offers. This is the final market clearing price at which milk quota is sold. All offers to sell quota at or below this price will be sold at the market clearing price and similarly all bids to buy quota at or above the market clearing price will be accepted. The remaining offers and bids will be rejected (DAFF, 2011a). The market clearing prices differ significantly between the co-operatives, as can be seen in Figure 1.

Buyers and sellers face certain rules when participating in the milk quota trading scheme. For example, if all or parts of the milk quota are sold, the farmer is not allowed to purchase, lease or receive any milk quota for a period of three years. Further, the milk allocated to the priority pool will not be returned to the farmer, even if the offered quota fails to sell. Buyers are subject to quantitative restrictions. The maximum quantity that can be purchased in each milk quota trading scheme is limited to 100,000 litres since 2010, which increased from 80,000 litres in 2008.

While the milk quota trading scheme is operated in advance of the relevant milk quota year, Irish farmers also have the option to avail quota during the milk quota year with the temporary leasing scheme. Producers have the opportunity to lease the part of their quota which they will not use during the current milk quota year into their co-operative pool. In turn, producers who require additional quota can apply to lease quota from the pool (DAFF, 2011b).

Finally, there is also the possibility to receive quota at the end of the milk quota year through the reallocation of unused quota. This scheme is designed for the event of a production level that exceeds national quota, and unused quota is then reallocated to eligible over-quota producers.

3. Empirical Approach

A cross-sectional farm level dataset is used in an optimisation framework to estimate the economic value of quota. Hennessy et al. (2009) used Irish National Farm Survey (NFS) data and FAPRI-Ireland price projections to estimate the economic value of milk quota in Ireland. Here a similar methodology is applied but the model is re-specified to simulate as closely as possible the conditions of the milk quota trading scheme as it is operated in Ireland.

The model structure is as follows. The objective function of an individual farmer, denoted by subscript i, is expressed as:

$$\underset{Q_i}{Max}\,\Pi_i = \sum_{t=0}^{T} \frac{1}{(1+r_i)^t}[\pi(M_{it}) - P_t Q_{it} - C(Q_{it})] \qquad (1)$$

where Π_i represents the net margin of farmer i, r is a discount factor, π denotes the gross output from milk quota (M_{it}) in period t, Q_{it} denotes the quantity of quota farmer i decides to purchase or sell in period t, and P_t and C are the associated price and quantity.[4] This implies that the second component in the square brackets in equation (1) is the quota investment in period t which is simply the price of quota in that period times the quantity of quota purchased and the final component represents adjustment costs to the farmer. The farmer chooses a quantity Q_{it} of quota to purchase (or sell) in each period (year) that maximises a discounted stream of annual net margins between the current period $t=0$ and the period when quota is abolished, $t=T$. The solution to equation (1) represents the demand or supply of milk quota by farmer i in each time period associated with expansion of milk production by amount Q_{it}. Adjustment costs include for example, additional housing, land, labour, etc. In the case where a farmer sells quota, the cost of quota includes the margin foregone due to the reduction in milk production less the net margin gained from reallocating resources to the best alternative enterprise.

Since it is assumed that milk deliveries M_{it} are equal to the farm's milk quota in period t, then:

[4] To avoid notational clutter the profit function displays only milk quota (M_{it}) in its argument. It also comprises a vector of other factor inputs as well as cost and revenue coefficients.

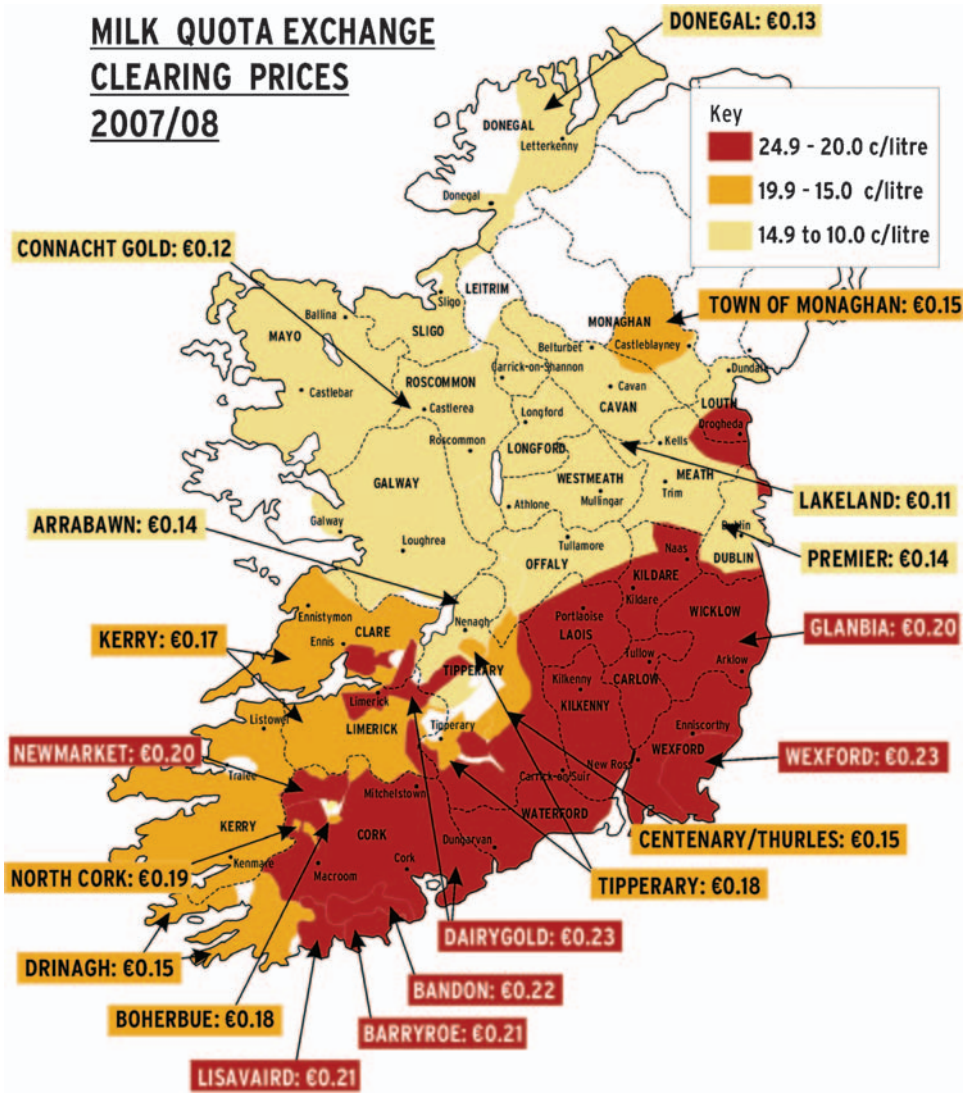

Figure 1: Milk Quota Exchange Clearing Prices

$$M_{it} = M_{it-1} + Q_{it}. \tag{2}$$

Thus milk deliveries in period t are equal to milk deliveries in period $t-1$ plus quota purchased (or less quota sold) in period t. Equation (2) therefore defines the quota constraint that limits the farmer's optimisation problem. The Lagrangian for farm i's maximisation problem is:

$$L_i = \sum_{t=0}^{T} \frac{1}{(1+r_i)^t}[\pi(M_{it}) - P_t \cdot Q_{it} - C(Q_{it})] + \sum_{t=0}^{T} \lambda_{it}(M_{it-1} + Q_{it} - M_{it}). \tag{3}$$

Here λ_{it} represents the marginal value to farmer i from relaxing the milk quota constraint by one unit - the shadow price of milk quota - specifying the marginal effect of an increase in M_{it} on the value of the farm's discounted net margins between $t=0$ and $t=T$ discounted to time 0. The economic value of quota is derived based on the aggregated effect, as explained in the following paragraphs.

The constrained optimisation problem defined by equations (1) and (2) is solved using estimates of farm level adjustment costs, price and cost projections coming from the FAPRI-Ireland model (Binfield et al., 2008) and NFS (Connolly et al., 2007) data for Ireland. Estimates of the marginal revenue product (economic value) of milk quota are derived for a sample of dairy farms for the period up to 2015. In this analysis it is assumed that the national milk quota remains binding up to 2015 and therefore the quota produces a profit up to and including the year 2014. Aggregation of these results generates an empirical estimate of the aggregate demand for milk quota, while the distribution of farm reservation demands against existing holdings of quota indicates the trades of quota between farms. Within the model each farmer's purchase is limited to 80,000 litres to reflect the constraints imposed on quota purchase in the 2008 milk quota exchange.[5]

In this analysis it is assumed that farmers increase milk production on a phased or incremental basis. They begin by increasing the dairy specialisation of the farm, by removing all male animals from the farm and

[5] Please note that our analysis refers to the milk quota market in 2008, and the limit to buy quota was 80,000 litres in 2008. Our analysis is based on 2008 as milk prices in 2009 were at an unusual low level, thus unlikely to provide a representative analysis of the quota market.

retaining only dairy cows and replacements. This is considered the low cost stage of expansion. Once this stage of expansion has been exhausted, farmers will move beyond their own resource base and rent more land and acquire additional resources. This is considered the high cost stage of expansion. The extent to which farmers can expand at the different stages is estimated for each farmer in the NFS on the basis of their livestock numbers and land area. The costs associated with the two stages of expansion are taken from Shalloo and Dillon (2006). The full details of costs associated with each stage of expansion are outlined in Appendix A. It should be noted that the analysis does not factor in the possibility of expanding milk production by changing the production system, i.e. moving to a more intensive production system or a higher genetic merit cow.

The demand and supply price of milk quota is estimated for each farmer in the NFS. The 2008 economic value is estimated, this estimate is based on the net margins earned from each unit of quota in every year from 2009 to 2014 inclusive. Farms are grouped according to their geographic location and individual farm demand and supply prices are summed using the NFS weights to arrive at aggregate supply and demand curves for milk quota in various regions. The intersection of regional supply and demand curves are interpreted as the economic value of quota.

4. Data

In the analysis of economic value of quota, data on all manufacturing milk dairy herds in the NFS[6] dataset are used; this consists of 343 farms that are weighted to represent the national population of 19,600 dairy farms (Connolly et al., 2007). The NFS collect enterprise specific variable costs but fixed costs are recorded on a whole farm basis. For this analysis total costs are considered, although excluding the cost of owned resources such as land or family labour. Fixed costs are allocated to the dairy enterprise on the basis of gross output share. All technical coefficients, as recorded by the NFS, are assumed to remain static over the period.

To simulate the milk quota exchange scheme as closely as possible the sample of dairy farms are disaggregated by region. While it would be desirable to represent all exchange schemes, the dataset is neither sufficiently large nor geographically representative to enable such an analysis. Instead, the dataset is disaggregated into four regions: border, midlands and western (BMW), the south-west (SW), the east and the south.[7] Each of the four regions has unique characteristics regarding dairy production. While the south and the south-west are mainly dairy production regions on good soils, the BMW region is characterized by lower stocking density based on poorer soils and higher rainfall areas.

Table 1 presents some summary statistics for the four regions. For comparative purposes direct costs, gross and net margins are presented in a per litre figure. Direct costs represent the dairy production costs, such as feeding stuffs, fertilisers and veterinarian costs. Gross margins are defined as gross output minus direct costs, with gross output being total milk sales less purchased livestock. Net margins are calculated as gross margins minus overhead costs of production and include for example depreciation of machinery, buildings and land.

With a total quota size of 1,382 million litres, over a third of the national quota is located in the south region. Farms in the BMW region are characterized by smaller herds and smaller milk quota sizes per farm in comparison to the remaining regions.

On a gross margin basis, the east region has the highest profitability, with a gross margin of 17.3 cent per litre; however when overhead costs are factored in and net margin is considered the south-west is the most profitable region with an average net margin of 7.4 cent per litre. The east has the largest expansion capacity on existing resources with the average farm having capacity for 24 additional cows. The expansion capacity is based on the assumption that half of the cattle herd is replaced by dairy cows, while also considering replacement of the current dairy herd.

In terms of milk prices, it is evident from Table 1 that farmers receive different milk prices in Ireland[8]. This is due to different prices paid by the various co-operatives. For example, farmers in the south region generally receive higher milk prices than farmers in the remaining regions. Further, farmers in the BMW region get paid less for their milk than farmers in the south-west and east region.

Figure 2 presents the milk price projections under a baseline policy scenario; this assumes that milk quotas remain in place and binding until 2015. Data for 2006 to 2010 are actual average national farm level milk prices (Donnellan and Hennessy, 2011). Prices from 2010 to 2014 are projections produced by Binfield et al. (2008) using the FAPRI-Ireland model.

5. Results

Development of Quota Prices

Before presenting the estimates of the economic value of milk quota, the development of milk quota exchange prices is explored. Individual data on quota trade prices are available for the main co-operatives, see Table 2. For the purposes of this analysis the co-operatives are grouped into four regions as described in section 4. The average quota price for each region is calculated as the quota price weighted by the volume of milk sold in each co-operative.

As is evident from Table 2, there is a large variation in market quota clearing prices between the regions. For example, in the fourth exchange market quota clearing prices ranged from 17 cent per litre in the BMW region to 41 cent per litre in the south region. Further, there is a noticeable tendency toward decreasing quota prices over time, which is explained by the approach of the abolition of milk quotas. The development of the

[6] The NFS is a member of the Farm Accountancy Data Network of Europe. A stratified nationally representative random sample of approximately 1,200 farms is surveyed annually.

[7] BMW region = Louth, Leitrim, Sligo, Cavan, Donegal, Monaghan, Galway, Mayo, Roscommon, Longford, Offaly, Meath, Westmeath and Dublin. South-west region = Kerry, Clare, Limerick and Tipperary. East region = Kildare, Wicklow, Laois, Carlow, Kilkenny and Wexford. South region = Waterford and Cork.

[8] In late February 2012 €1 was approximately equivalent to £0.85 or U$1.35 (www.xe.com)

Table 1: Regional Variability – Summary Statistics

Summary Statistics	BMW *N=65*	South-West *N=76*	East *N=80*	South *N=122*
Weighted population	4,893	5,961	2,796	5,949
Percentage of national quota (%)	22	29	15	34
Total Quota (millions of litres)	894	1,175	610	1,382
Quota size (litres)	182,000	197,000	218,000	232,000
Deliveries per cow (litres)	4,740	4,330	4,570	4,700
Number of dairy cows	35.4	44.0	45.7	46.4
Milk price received (€)	0.261	0.263	0.263	0.265
Direct cost per litre (€)	0.112	0.102	0.102	0.110
Gross margin per litre (€)	0.169	0.166	0.173	0.156
Net margin per litre (€)	0.062	0.074	0.068	0.061
Expansion capacity (cow numbers)	11	15	24	16

Source: National Farm Survey (2007)

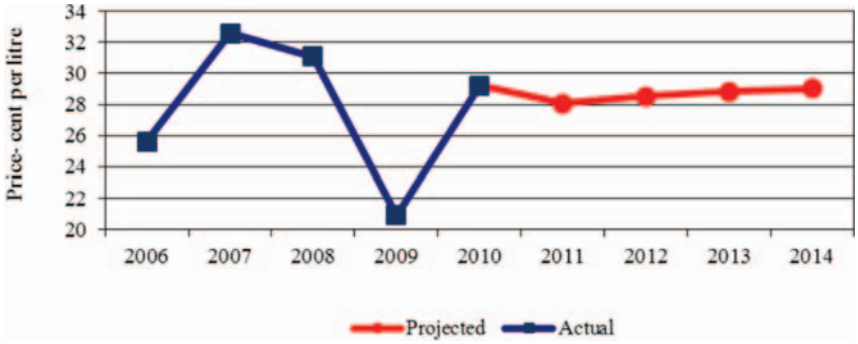

Figure 2: FAPRI-Ireland Farm-Level Milk Price Projections for Ireland

various prices is depicted in Figure 3. This figure presents the average market quota clearing price for each region and the national average milk price that prevailed at the time of each milk quota exchange.[9]

The milk quota prices follow the development of milk prices quite closely, although to a lesser extent in the BMW region. Overall, quota prices peaked at the fourth exchange which took place at the beginning of 2008. In 2007, the national average farm level milk price was over 30 cent per litre and remained at this level in early 2008. However, a significant drop in milk prices occurred in the latter half of 2008 and milk prices decreased to an average of 20.9 cent per litre in 2009. As can be seen, quota prices collapsed in the fifth exchange, autumn 2008, following the milk price decline.

Economic Value of Milk Quota

Figures 4a and b present the estimated milk quota supply and demand curves for trade occurring at the end of 2007 for the four regional quota markets, i.e. 2008 is the first year the quota provides a return and seven years of return are produced from 2008 to 2014 inclusive. These figures are derived from the previously explained optimization model (see section 3) and show the estimated overall quantity traded in the region (x-axis, volume litres) and the estimated milk quota price (y-axis). The intersection of the estimated demand and supply curve is interpreted as the economic value of milk quota for the specific region.

[9] The three months average milk price preceding the quota exchange scheme is used.

The results show that the estimated equilibrium economic value for milk quota in the BMW region is approximately 21 cent per litre compared to a milk quota price of 26 cent per litre in the east. The results from the optimization model also show that the markets in the south-west and south have a higher quantity of milk quota traded and the equilibrium values are also estimated to be higher. Our model predicts the highest milk quota equilibrium price in the south-west region with 35 cent per litre. The corresponding milk quota equilibrium price in the south is 29 cent per litre.

The variation in the estimated economic values of quota in the different regions is driven by the profitability of milk production in the region and the farm structure. More specifically, the supply price for milk quota is derived from net margins, which implies that farmers in regions with more profitable milk production are also looking for higher prices when intending to sell milk quota. Clearly, profitability of milk production is highly dependent on milk prices. The milk quota market is also influenced by the expansion capacity of farms, which indicates that farmers with lower expansion costs are also able to offer higher prices for additional quota. Further, the quantities demanded and supplied in the different regions also impact on the estimated economic values of milk quota.

In line with the actual milk quota exchange prices (see Table 2), our optimization model results also show considerable variation between the regions. The south-west region, for example, has the highest equilibrium price with 35 cents per litre (see Figure 4b), which is driven by the highest net margins of the four regions

Table 2: Milk Quota Exchange Clearing Prices for Selected Co-operatives

	2007/08		2008/09		2009/10		2010/11
Exchange Closing date for bids	1st 10/06	2nd 01/07	3rd 10/07	4th 01/08	5th 10/08	6th 01/09	7th 10/09
Co-operative							
Border, midlands and western							
Arrabawn	14	16	24	29	21	13	0
Connacht Gold	12	10	12	14	13	10	5
Donegal	13	12	13	14	10	0	7
Lakelands	11	11	13	14	14	10	5
Town of Monaghan	15	16	20	20	14	10	0
Average price	**13**	**14**	**15**	**17**	**16**	**11**	**5**
East							
Wexford	23	28	29	36	37	10	11
Glanbia	20	21	31	37	32	18	12
Average price	**20**	**21**	**31**	**37**	**32**	**17**	**12**
South-west							
Kerry	17	16	20	27	20	11	5
Dairygold	23	26	45	45	40	16	12
Tipperary	18	18	25	30	29	25	16
Average price	**20**	**21**	**28**	**38**	**30**	**15**	**10**
South							
Dairygold	23	26	45	45	40	16	12
Glanbia	20	21	31	37	32	18	12
Bandon	22	24	36	42	0	24	17
North Cork	19	20	30	29	19	0	0
Average price	**22**	**23**	**37**	**41**	**35**	**17**	**12**

All prices are milk quota prices expressed in cent per litre.
Source: Irish Department of Agriculture, Fisheries and Food

and, in addition, almost 30% of milk quota is located in this region (see Table 1). The south region, with an economic value for milk quota of 29 cent per litre, has the second highest value for milk quota (see Figure 4b), which is explained by the fact that this relatively small region holds over a third of the national quota. Further,

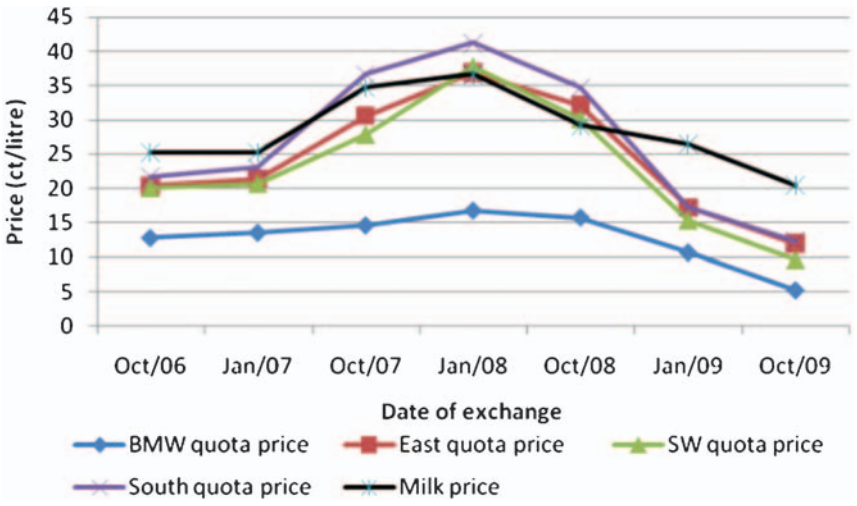

Figure 3: Development of Prices by Region

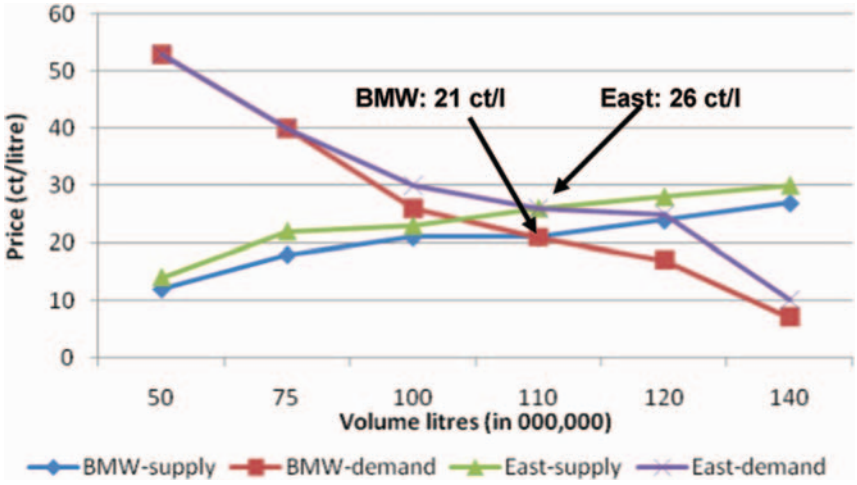

Figure 4a: Regional Milk Quota Market – BMW and East Region

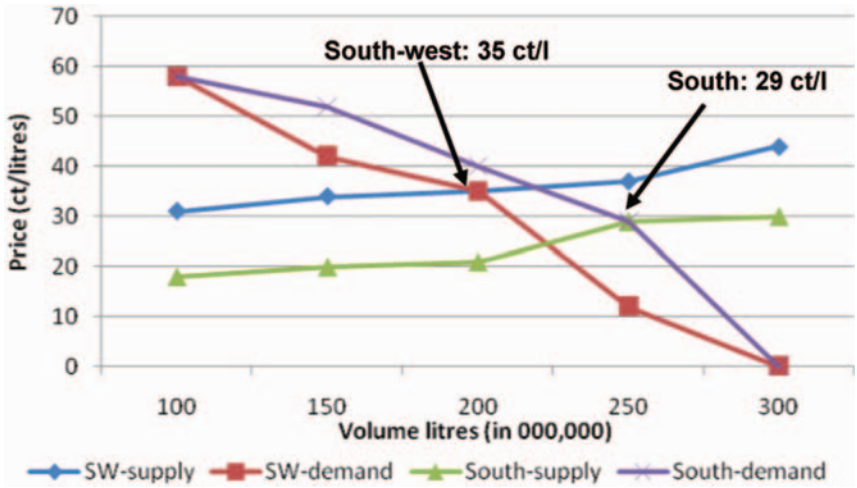

Figure 4b: Regional Milk Quota Market – South-west and South Region

milk prices received in this region are higher than in the remaining regions. In the east region (see Figure 4a), the estimated economic value of milk quota of 26 cent per litre is explained by the high expansion capacity (see Table 1). A high expansion capacity implies that farms can expand dairy farming at low costs, meaning that these farmers are able to pay more for additional quota due to lower expansion costs, i.e. a large number of male cattle that can be disposed and replaced with cows. Finally, the BMW region has the lowest estimated value of milk quota at 21 cent per litre (see Figure 4a), which is in line with the lowest milk price received and the highest direct costs in comparison to the remaining regions (see Table 1).

By comparing the estimates of economic value to the actual quota exchange prices recorded in the respective milk quota exchanges, some interesting findings emerge. Table 3 presents a comparison between the estimated economic value of milk quota and the average milk quota exchange price in each region for the end of 2007.

Based on our estimations of the economic value, farmers could afford to pay more for quota in the BMW and south-west region, suggesting that quota is undervalued in those regions. The average exchange price exceeds the estimated economic value of quota in the east and south of the country, indicating that quota is overvalued in those regions.

Close inspection of Table 3, reveals significant differences between the regions. For example, farmers in the BMW and the south-west region could afford to pay more for milk quota (based on the estimated economic value of milk quota) than the milk quota exchange price. This indicates that it could be profitable for farmers to acquire additional milk quota while the quota scheme is still in place when intending to expand milk production in the future. In contrast, our estima-

Table 3: Regional Economic Value of Milk Quota and Average Milk Quota Exchange Price per Region

Region	Economic value 2007	3rd Exchange price	Difference
		Cent per litre	
BMW	21	14	+7
East	26	31	−5
South-west	35	28	+7
South	29	37	−8

The respective co-operatives for each region are shown in Table 2.

tions also reveal that farmers in the remaining two regions overpay for quota. This is most significant for the south region, where farmers pay eight cents per litre more for additional quota than they could afford to pay based on our model estimations. Given the high milk quota exchange prices, farmers in these regions would be better off waiting to expand production until milk quotas are abolished or quota prices drop.

6. Conclusions

This paper presented a review of the development of milk quota exchange prices in Ireland and showed regional estimations of economic values of milk quota. By comparing actual milk quota exchange prices to the estimated economic values of milk quota, improved insight into the functioning of the milk quota market in Ireland is gained. The result provide insight as to where milk production is likely to move after milk quota expires and the results can also assist farmers in the decision whether and when to invest in additional milk quota. This is of particular relevance since the abolition of milk quotas in 2015 in the EU brings significant changes for dairy farmers, most importantly the possibility to expand production without restrictions.

This study showed that there has been a large variation in milk quota exchange prices between regions and also over the years. While the variation in milk quota prices over the years mainly followed fluctuations in milk prices, differences between the regions can partly be explained by profitability and characteristics of milk production in the particular region. Indeed, the results of our optimization model confirm this finding and consequently the estimated economic values for milk quota in the four regions differ considerably. For example, the estimated economic values of milk quota vary from 35 cent per litre in the south-west region to 21 cent per litre in the BMW region, which mirror the different levels of profitability and costs of production in those regions. When comparing the estimated economic values of milk quota to the actual milk quota exchange prices, differences between the regions are even more pronounced. More specifically, we find that farmers in the south and east regions overpay for quota, while farmers in the BMW region and south-west regions secure good value when investing in additional milk quota. Based on our model findings, farmers in the south and east region would be advised to postpone milk quota investment until prices drop or quotas are abolished. In contrast, farmers in the BMW and south-west region secure good value for additional milk quota and could thus afford to invest in additional quota while the scheme is still in place.

The high milk quota exchange price in the south region indicates strong demand for milk quota, which could be an indicator that farmers are eager to expand milk production in this region. Further, high milk quota exchange prices in the east in combination with high estimated expansion capacity, could also be a sign of potential expansion of milk production in this region. Further, evidence from co-operative supplier numbers suggests that farm-level structural change differed in Ireland. Structural change has been more rapid in the border and west of Ireland whereas it has been more sluggish in the south and east over the past decade. This may imply that farmers wishing to expand in the south and east regions have pent-up demand. Indeed, anecdotal evidence indicates that farmers in these regions are eager to get additional quota (Hennessy et al., 2009).

Overall, the findings of this study indicate the presence of a wedge between milk quota value, i.e. estimated economic value, and its traded price. Interestingly, the analysis also revealed that the difference between the economic value of quota and the milk quota exchange price is not in the same direction for all regions. Thus, the imposition of a regional restriction on milk quota trade is controversial because it inevitably leads to different trade prices in different regions. While these regional differences may be partly explained by the economics of production, other factors such as the influence of short-term market development and farmers' behaviour also seem to play an important role.

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Appendix A: Details of Adjustment Costs

The first stage of expansion up to the threshold level X_i involves increasing cow numbers by disposing of non-dairy livestock (ND) – typically beef cattle.[10] To allow for replacements each non-dairy livestock unit is equal to one dairy cow less the farm's herd replacement rate (RP_i). The quantity of extra milk then depends on the yield record on farm i in period t ($Yield_{it}$). Hence, the extent of this expansion differs with each farmer's resource base and technical efficiency; this is expressed as follows:

$$X_i = 0.5ND_i(1 - RP_i) \times (Yield_{it}) \quad (4)$$

The incremental adjustment cost per litre (C_{ix}) for farm i associated with this stage of expansion are derived from:

- Replacing a beef livestock unit with dairy results in a net increase in labour of 23 hours per cow. The cost of extra labour ($Wage_t$) is assumed to be €12 per hour, increasing over subsequent time periods according to projected wage rate inflation.
- Infrastructure costs in the first expansion stage ($InfraX$) comprise the conversion of existing non-dairy accommodation (estimated cost of €300 per cow) plus upgrading of dairy facilities (estimated cost of €406 per cow).
- Infrastructure costs are fully written-down over a 10-year period on a straight-line basis. The investment is financed using a 10-year term loan at an interest rate of 6 per cent. Interest in each year for the amortized loan is computed by applying the appropriate period compound interest factor ($IntFac_t$) to the sum invested.
- The cost of retaining additional replacement heifers.
- The foregone profit per livestock unit on Non-Dairy livestock ($NDProf$), excluding the decoupled payment, is estimated from NFS data. In 2006, the average profit per beef livestock unit was €103.

Thus the adjustment cost per litre of quota investment in this stage would be:

$$C_{ix} = \frac{23(Wage_t) + (0.1 + IntFac_t)(InfraX) + NDprof_{it}(1 + RP_i)}{(Yield_{it})} \quad (5)$$

The second stage of expansion which occurs after threshold X_i is more costly as it involves acquiring additional land and increasing overall livestock numbers. The costs are as follows:

- Land rental costs are estimated to be €268 per year hectare ($Rent$). The additional land required is dependent on the stocking rate of the farm (SR_i).
- Full labour costs are assumed in this expansion stage involving annual input of 35 hours per cow. The wage rate ($Wage_t$) is €12 per hour in the first time period and increases in subsequent time periods.
- Infrastructure costs ($InfraY$) in the second stage involve expansion of milking facilities and construction of new housing at a combined cost of €1,633 per additional cow.
- Infrastructure costs are fully written-down over a 20-year period on a straight-line basis. The investment is financed using a 20-year term loan at an interest rate of 6 per cent. Interest in each year for the amortized loan is computed by applying the appropriate period compound interest factor ($IntFac_t$) to the sum invested.
- Additional cows are purchased for an average price of €1,320 ($CowCost$) and the interest rate (Int_t) on capital invested in the extra cows is assumed to be 6%.

Therefore, the incremental adjustment cost per litre of quota investment in this stage can be written as:

$$C_{iy} = \frac{\left({Rent}/{SR_i}\right) + 35(Wage_t) + (0.1 + IntFac_t)(InfraY) + (1 + Int_t)(CowCost)}{(Yield_{it})}. \quad (6)$$

[10] As data on land fragmentation is not available, it is assumed that only half of the non-dairy stock can be replaced with dairy cows.