Application of an optimisation model for analysing production seasonality in the Irish milk processing sector

KARIN E. HEINSCHINK[1], LAURENCE SHALLOO[2] and MICHAEL T. WALLACE[1]

ABSTRACT

Ireland's dairy sector is characterised by pastoral spring-calving systems and seasonal milk production at national level. This production seasonality initiates various implications at processor level, such as poor plant capacity utilisation in the off-peak season or a requirement for seasonal labour, which impose extra costs on the processor and limit their options as to which markets can be serviced. An optimisation model was developed to analyse the impact of production seasonality on the Irish dairy processing industry regarding processor gross surplus (*Surplus*), costs of milk collection and handling, processing, product storage and labour as well as on product mix, plant and labour capacity utilisation and the marginal producer milk price (*MPMP*). Three scenarios with differing milk intake curves were examined whereby it was found that a flatter intake pattern incurred less variation in the *MPMP* and capacity utilisation in addition to a higher *Surplus* and a larger proportion of more profitable products in the product mix *vis-à-vis* seasonal patterns. As expected, these results suggest that a producer supplying milk in line with a nationally seasonal production pattern receives lower milk payments since the seasonality-related costs are fed back from the processor to the producer via a lower producer milk price.

KEYWORDS: Milk production seasonality; processor profitability; dairy product mix; marginal producer milk price; optimisation model; linear programming

1. Introduction

In pastoral milk production systems, the dairy herd's calving dates are matched with the grass-growing season's start in order to maximise the intake of cost-efficient grazed forage, effectively resulting in a seasonal milk production pattern. The producer benefits from reduced feed costs and thus lower production costs per kg of milk, however the production system needs to be flexible to ensure adverse climatic conditions can be managed through the use of diet supplementation by means of more expensive concentrates. Seasonal supply at producer level initiates a variety of challenges in dairy processing and auxiliary activities, resulting in implications for milk transport, storage and financing. For the off-peak season, implications include persistent plant and labour capacity underutilisation which potentially necessitates the closing down of plants for a part of the year, as well as higher raw milk collection and product storage costs (Downey and Doyle, 2007, Hennessy and Roosen, 2003, Prospectus, 2003, Quinlan et al., 2011). Since output capacities of more lucrative products are usually fully exploited during peak months, the 'excess' milk supplies in those months are typically manufactured into less profitable commodities that involve reduced market returns and increased finance and storage costs. In addition, milk composition changes in the course of lactation; the suitability of some late-lactation milk for various products, particularly cheese, is limited with respect to processability, storability and desired product properties (Guinee et al., 2007, Downey and Doyle, 2007, Phelan et al., 1982).

Ireland's dairy industry has the highest production seasonality within the EU with a peak-to-trough ratio (PT ratio) of 4.9:1 in 2009. The vast majority, namely 21 EU member states, ranged from 1.1:1 to 1.3:1 (EC, 2010b). In Ireland, 18 processing enterprises (derived from DAFF, 2010b) purchased approx. 5.2m tonnes of raw milk, of which 92% were produced domestically (CSO, 2011) in 2009. Of the total domestic raw milk produced, 10.3% were manufactured into liquid milk (509,600 tonnes), the remainder of the national product mix consisted mainly of cheese (157,500 tonnes), butter (126,000 tonnes), skim milk powder (SMP) (113,000 tonnes), chocolate crumb (40,500 tonnes), proteins (30,000 tonnes) and whole milk powder (WMP) (25,000 tonnes) (IDB, 2010, National Milk Agency, 2010). Dairy exports accounted for €2.7bn[3], or 30% of agri-food and drinks exports in 2009 (DAFF, 2009). In the same year, an estimated 5,000 persons were employed in the dairy processing sector (CSO, 2011).

Due to the progressing deregulation of EU dairy markets, competitive pressures are expected to increase as national milk output will no longer be limited by milk

[1] School of Agriculture, Food Science and Veterinary Medicine, University College Dublin, Dublin, Co. Dublin, Ireland.
[2] Livestock Systems Research Department, Animal and Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland
[3] In July 2012, €1 was worth approximately £0.79 and $US1.22

production quota post 2014/15 and prices are assumed to settle closer to world market prices. In this context, Ireland has been recommended to examine the implications of milk production seasonality and the future structure of the processing sector (Teagasc, 2009). However, there are contrasting financial implications of seasonality for producers and processors. On the one hand, seasonal milk production is favoured at farm level because it allows producers to minimise production costs by optimising the use of grazed pasture. On the other, seasonality imposes extra costs on milk processors in terms of additional plant capacity to handle peak supplies, poor off-peak capacity utilisation and reduced product mix flexibility. A key challenge concerns how to reconcile these divergent producer-processor interests to formulate a more cohesive strategy that maximises returns to the industry as a whole.

Addressing such issues becomes more urgent in the context of abolition of the milk quota. With expected expansion of milk supplies processors must decide whether investments should be made to further support a seasonal milk production, or whether present capacities could be used more efficiently by means of smoothing milk intake pattern.

The economic sustainability of seasonality in dairy markets has been studied (FAO, 2010, Keane and Killen, 1980) and 2 fundamentally different strategic options with important consequences for the entire value chain have emerged for processors: accepting or evening out a seasonal milk intake curve (Keane, 2010). Maintenance of a seasonal supply profile results in a 'production-led', price-sensitive, commodity-based dairy industry with lower milk production costs on the one hand, but a variety of inefficiencies in the processing and marketing of dairy products on the other. In contrast, a flat milk supply curve facilitates the design of a 'market-led' product mix comprising less price-sensitive, value-added items throughout the year as well as better utilisation of fleet, plant, storage and labour capacities (Downey and Doyle, 2007). This can be achieved by encouraging producers to ensure year-round dairying particularly with the aid of milk price incentives (Harte and O'Connell, 2007) or, where geographically feasible, through imports of raw milk during months of low intake. Both measures raise the costs of raw milk.

The usefulness of optimisation models to solving problems in the agri-food industry has been widely acknowledged. Optimisation techniques have been used at milk processor level for analysing milk pricing mechanisms, the value of milk components, product mix and profitability in dairy processing (Bangstra et al., 1988, Breen et al., 2003, Burke, 2006, Papadatos et al., 2002). However, there has been little, if any, research that has modelled the implications of production seasonality for a milk processor. A few studies have used optimisation techniques to analyse milk production seasonality at farm level. For example, Davis and Kirk (1985) and Killen and Keane (1978) used farm level linear programming models to analyse the economic aspects of changing seasonal milk production patterns in Northern Ireland and the Republic of Ireland, respectively. They concluded that the interdependencies of milk production, collection and processing should be accounted for and that changing the distribution of milk production is justified only if this resulted in lower costs for the entire system. For example, a flatter milk intake curve may improve the processor's capacity utilisation and profitability throughout the year; however, if the additional production costs caused thereby at farm level exceed the economies at processor level, the authors recommend not to pursue seasonality changes.

Given this context, the objective of this paper is to analyse the financial consequences of seasonality for the Irish milk processing industry. A milk processing optimisation model is presented in which the objective function maximises a dairy processor's annual gross surplus subject to processing capacity and milk intake profile. Scenario analysis provides the opportunity to evaluate the impact of changes in milk production seasonality on processor profitability, seasonality costs, product mix, plant and labour capacity utilisation, marginal milk solids values and marginal producer milk price.

2. Method

Model output

A milk processing model was developed for the analysis of profitability based on various milk intake patterns or processing capacities.[4] The model was formulated as a single-criterion, multi-period linear programming problem which identifies the maximum annual processor gross surplus (*Surplus*, €) and a corresponding optimum production plan at monthly intervals for a time horizon of one calendar year. The optimum production plan maximises the processor's annual *Surplus* subject to its resource constraints comprising monthly raw milk supplies and processing capacities. Furthermore, the model solution illustrates the impact of milk production seasonality on selected costs (€), including raw milk collection and handling, product processing, labour, storage and product mix, as well as the marginal values of the milk solids (*SolidsMV*, €/kg solid) fat, protein and lactose. The *SolidsMV* allow for calculating the marginal producer milk price (*MPMP*, €c/kg raw milk). It should be noted that the price payable to the milk producers is covered by *Surplus*. The surplus-maximizing product mix is subject to a set of technical constraints addressing, for instance, milk solids contents and output capacities (Figure 1).

Processor gross surplus, product gross margin and milk collection and handling costs

The objective function (1) calculates *Surplus* (€) as the product gross margin generated from the production plan (*Margin*, €), reduced by the variable costs arising from raw milk collection and handling activities (*CollHandVC*, €) and total fixed costs (*FC*, €).

$$\text{Max.}\, Surplus = Margin - (CollHandVC + FC) \qquad (1)$$

The *CollHandVC* comprise the costs of all raw milk collection, assembly, separation and standardisation activities for the total raw milk volume processed.

[4] A technical annex providing a more detailed description of variables and equations is available from the corresponding author upon request.

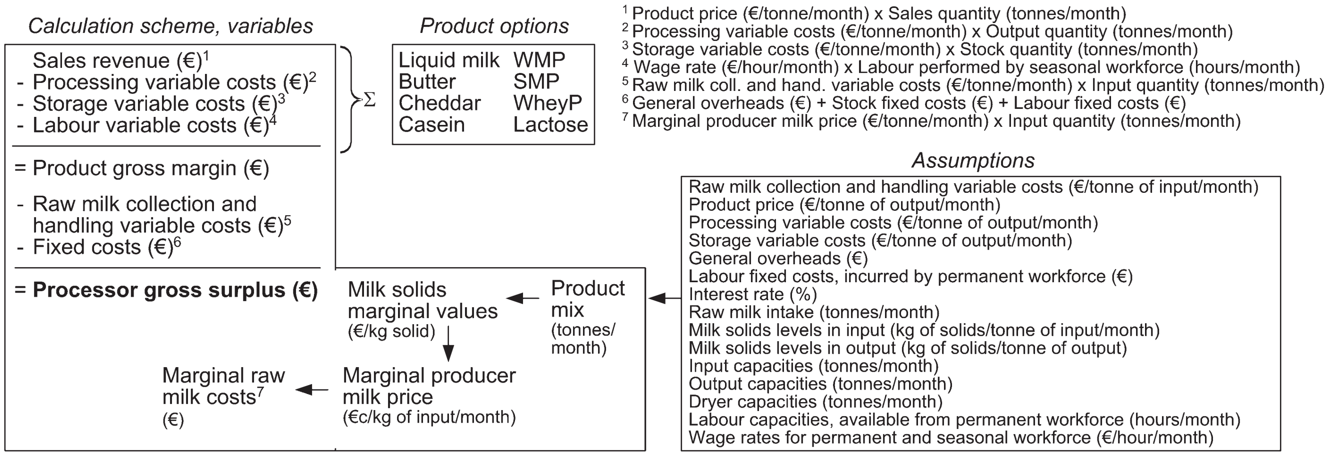

Figure 1: Conceptual framework

Margin is defined as sales revenue (*SalesRev*, €) less variable costs of processing milk into the final product (*ProcessVC*, €), labour (*LabourVC*, €) and product storage (*StorageVC*, €); where t =monthly time period (2). In the equations listed in this section a subscript t is used to denote variables or parameters that are defined on a monthly basis in the model. Omission of the t subscript denotes that the variable is determined at the annual level.

$$Margin = \Sigma_t \, SalesRev_t - (ProcessVC_t + StorageVC_t + LabourVC_t) \quad (2)$$

Milk solids, input and output capacities

Product yield (*Output*, tonnes) is limited by product composition (SolidsO, milk solids levels in output, kg solids/tonne of output) as well as by the quantity (*Input*, tonnes) and quality (SolidsI, milk solids levels in input, kg solids/tonne of input) of raw milk available for processing.

For each unit of milk solid allocated to a product, the amount of solids available from the milk pool is reduced by 1 unit. SolidsI are determined on a monthly basis in order to reflect the variability of raw milk composition which naturally occurs in the course of lactation. This is particularly relevant in an environment characterised by a seasonal milk supply profile as a dairy processor's production possibilities change during the year due to fluctuating quantities of milk components available for processing and the ability to process some of those components into certain final products.

Furthermore, the model predefines maximum input capacities (tonnes/month) depending on raw milk availability or intake capacity, and output capacities (tonnes/month) for individual products as determined by product processing capacity and marketing considerations.

Sales, stock levels and storage-related costs

Due to the perishable nature of milk, a seasonal intake curve will result in a seasonal production of dairy products which is in conflict with a relatively constant demand throughout the year (Killen and Keane, 1978). By dividing total annual output by 12 it is assumed in the model that product sales (*Sales*, tonnes/month) are constant throughout the year.

Any mismatch between monthly product yield and sales has implications for stock levels and stock-related costs. When product manufacture exceeds *Sales*, the unsold quantity is put on stock (*Stock*, tonnes/month), and when product manufacture falls short of demand, the quantity required to satisfy demand is taken from *Stock*. To account for the opportunity costs of resources tied up in output on *Stock* (*StockFC*, stock fixed costs, €), interest is charged based on the variable costs of processing, storage, labour, the value of milk components and the length of storage; where o = output, product line; s = type of milk solid; ProcessUVC[5] = variable costs of processing input into output per unit of output (€/tonne); LabourUVC = variable costs of labour per unit of output (€/tonne); StorageUVC = variable costs of storage per unit of output (€/tonne); IR = annual interest rate (%) (3).

$$StockFC = \Sigma_t \Sigma_o \Sigma_s (\mathrm{ProcessUVC_{ot}} + \mathrm{StorageUVC_{ot}} + \mathrm{LabourUVC_{ot}} + \mathrm{SolidsO_{os}} \times SolidsMV_{st}) \times Stock_{ot} \times (\mathrm{IR}/12) \quad (3)$$

Labour capacities and costs

The optimum product mix determines the total number of labour hours required, and the work hours available from permanent workforce are specified prior to running the model. When the permanent workforce cannot cover the workload required for the optimum production plan, seasonal staff are hired. Labour by seasonal workforce is all labour required for the product mix less the hours contributed by the permanent staff. Whereas wages paid to the permanent workforce qualify as fixed labour costs (*LabourFC*, €), those payable to the seasonal workforce are considered variable labour costs (*LabourVC*, €).

[5] UVC denotes 'Unit Variable Cost'.

Fixed costs

FC (€) are the total of *LabourFC* (€), *StockFC* (€) and general overheads (OverhFC, €, such as depreciation of plant and equipment, administration, managerial salaries).

Milk solids marginal values and marginal producer milk price

The marginal value (MV), or shadow price, of a limiting resource expresses how much can be spent on an extra unit of the resource without reducing the objective value, i.e. the *Surplus*, when other model specifications remain unchanged. The *MPMP* (€c/kg raw milk) is computed from the *SolidsMV* as indicated in the model solution, multiplied by the milk solids in raw milk (SolidsI, kg solids/tonne of input), divided by 1000 to scale to kg, and finally reduced by a volume charge (*VolCharge*, €c/kg input) based on *FC* plus *CollHandVC* (4a, 4b):

$$MPMP_t = \Sigma_s \left(SolidsMV_{st} \times \mathrm{SolidsI_{st}}/1000 \right) - VolCharge_t \tag{4a}$$

$$VolCharge_t = (CollHandVC + FC)/\Sigma_t\, Input_t \tag{4b}$$

Seasonality costs

A seasonally operated dairy processing plant registers additional costs that could be avoided or reduced with a smooth production profile. These seasonality costs (*SeasonalityC,* €) are calculated as the difference between key financial results for a scenario with a seasonal milk intake curve and a reference scenario with a smooth milk intake curve (Δ). In this paper, *SeasonalityC,* which were computed post-optimisation, comprise (a) certain costs arising from the processor's activities (*SeasonActivC,* €), i.e. raw milk collection and handling, processing, storage and labour, and (b) *Surplus* foregone due to a less profitable product mix (product mix costs, *SeasonMixC,* €) imposed by seasonality of raw milk supply. In other words, *SeasonActivC* stem from the output produced in the individual scenarios (5a), whereas *SeasonMixC* originate from the output *not* produced in the seasonal scenarios *vis-à-vis* a smooth raw milk intake pattern (5b):

$$SeasonActivC = \Delta\,(CollHandVC + ProcessVC + StorageVC + StockFC + LabourVC + LabourFC) \tag{5a}$$

$$SeasonMixC = \Delta\,(Surplus - SeasonActivC) \tag{5b}$$

3. Data

Financial data

Collection and handling costs per unit of raw milk (€/tonne) (Table 1) were taken from a milk transport model developed by Quinlan (2011) for Ireland whereby the transport model was run for each scenario as specified in this paper.

Product prices were obtained from price records on national (EC, 2010a) and international (Productschap Zuivel, 2010) markets. An annually standardised wholesale price was computed for manufactured dairy output as the 36 month average from January 2008 to December 2010. The liquid milk price (Young, 2009) was estimated as a percentage of the retail milk price reported for 2009 (63.9%) (derived from Young, 2009, CSO, 2011, National Milk Agency, 2010) (Table 2).

Product variable costs comprised (a) processing: fuel and power, added ingredients, packaging, transport, losses, effluent, interest and other direct expenses, (b) labour and (c) storage. Historical processing cost data (Breen, 2001) were updated for inflation, and, where applicable, adjusted for productivity increases (EC, 2010b, IPCC reports, processor annual reports, CSO, 2011) to 2009 level, and validated via industry consultation. The hourly wage rate of €21 charged for both permanent and seasonal workforce was taken from CSO (2011). Storage costs were derived from consultations with milk processors and storage companies (industry consultation).

The interest rate applied to calculating interest on bank loans and opportunity costs of storage was set to 6.8% per annum (derived from processor annual reports).

Overhead costs of the representative processing plant were €3.99m per annum in all three scenarios. This was equivalent to €c1.46 per kg of raw milk processed which was regarded as typical for Irish milk processors in 2009 (industry consultation). Overhead costs included depreciation, insurance, rent, R&D, interest, management, quality control and central IT and administration (industry consultation).

Plant scale

It was decided to specify a synthetic plant for the scenarios modelled which processes the national average of domestic raw milk intake (2009: 273,746 tonnes) while availing of processing capacities which were calculated as product-line averages. For this purpose, the milk pool was specified as total domestic milk intake divided by the total number of processors, and each

Table 1: Raw milk collection and handling costs

CollHandUVC[a]	Baseline €/tonne	Smooth €/tonne	Seasonal €/tonne
Jan	21.83	9.73	51.45
Feb	15.71	9.86	50.01
Mar	9.42	8.63	11.67
Apr	7.98	8.45	7.82
May	7.50	8.26	7.33
Jun	7.63	8.44	7.64
Jul	7.92	8.49	7.94
Aug	8.48	8.68	8.38
Sep	9.05	8.64	8.78
Oct	10.81	9.74	10.38
Nov	14.66	9.90	11.77
Dec	21.19	9.90	52.44
W.avg.[b]	9.73	9.01	10.01

[a]CollHandVC = collection and handling costs per unit of raw milk (€/tonne/month), adapted from Quinlan (2011).
[b]W.avg. = weighted average.

Table 2: Product prices per month, variable costs of processing, labour and storage per unit of output and month; output capacities per month

Output	Product price €/tonne/month	Processing costs ProcessUVC €/tonne/month	Labour costs LabourUVC €/tonne/month	Storage costs StorageUVC €/tonne/month	Processing capacities tonnes/month
Liquid milk	627[b]	200	24	0.00	2,831
Butter	2,620[c]	258	12	8.13	1,050
Cheddar	2,759[c]	306	36	5.80	1,875
Casein	6,480[d]	241	154	5.80	357
WMP[a]	2,471[e]	265	71	3.14	Dry[g], 298
SMP[a]	1,973[c]	217	71	3.14	Dry[g]
WheyP[a]	535[e]	216	71	3.14	Dry[g], by-prod[h]
Lactose	577[d]	250	71	3.14	By-prod[h]

[a]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder.
[b]Derived from Young (2009), NMA (2010) and CSO (2011).
[c]Prices for the Ireland, average Jan 2008 to Dec 2010 (EC, 2010a).
[d]Prices for the USA, average Jan 2008 to Dec 2010 (Productschap Zuivel, 2010).
[e]Prices for the Netherlands, average Jan 2008 to Dec 2010 (Productschap Zuivel, 2010).
[f]Breen (2001), adjusted for inflation and productivity increases (EC, 2010b, IPCC reports, processor annual reports, CSO, 2011) and validated by industry consultation.
[g]Products utilising drying capacity: WMP, SMP, WheyP.
[h]By-products: WheyP, Lactose.

product's processing capacity was computed as national output divided by actual number of processors manufacturing the product in question. This approach was chosen to ensure that production capacities would be representative of typical production scales for individual products within the industry.

Input: Raw milk quantity and composition

The monthly milk volume available for processing was calculated as Ireland's creamery domestic milk intake at national level in 2009 (CSO, 2011) and divided by the number of processors in 2009. The lactation curves (Olori et al., 1999) were applied in order to estimate milk volume and milk composition according to seasonal calving pattern. To accommodate the fact that these levels vary according to stage of lactation and month of calving, a dynamic link was established between milk pool, calving pattern and lactation curves, ensuring that the amount of milk solids available for the production plan was automatically recalculated as soon as the monthly calving distribution changed.

The milk solids types considered in the milk pool and products were fat (FAT), protein (PRO) and lactose (LAC). PRO was further subdivided into casein protein (CPRO) and whey protein (WPRO); non-fat solids (NFS) were the aggregate of PRO plus LAC. The item NFS was introduced to allow for flexibility in product composition where FAT levels are standardised while PRO and LAC levels vary in line with raw milk composition (see milk powders). Hence, total NFS allocated to 1 unit of output remained unchanged while the proportion of PRO or LAC within the NFS collective corresponded to actual levels contained in the milk pool. PRO was subdivided into CPRO (82% of PRO) and WPRO (18% of PRO) (Fox and McSweeney, 1998).

Output: Product types and composition

A catalogue of 8 product options was specified, including those which are particularly important in Ireland's national product mix: liquid milk, butter, cheddar cheese (Cheddar), casein, whole milk powder (WMP), skim milk powder (SMP), whey powder (WheyP) and lactose (Table 3). PRO and LAC levels in liquid milk, WMP and SMP were allowed to fluctuate in line with monthly raw milk composition as opposed to a standardised product composition for all other items (Breen, 2001; IDB, Dublin, Ireland, personal communication, McCance and Widdowson, 2002) throughout the year. The logic is that, although FAT contents are standardised in the manufacture of liquid milk and milk powders in Irish dairy processing facilities, PRO and LAC levels typically are not; instead, the amount of PRO and LAC contained in the milk pool goes unaltered into the final product (Teagasc, Fermoy, Ireland, personal communication). Unlike the other product options, cheese and casein products only utilise the CPRO component of milk protein only; the remaining WPRO goes into whey, which, is subsequently manufactured into the by-product WheyP (Southward, 1998).

Input and output capacities

The volume of raw milk to be processed was constrained by the milk pool available (tonnes/month). Likewise, a monthly upper limit was determined for selected manufactured outputs (Table 2). Liquid milk output (tonnes/month) was determined not to exceed 10.3% of the annual milk pool, which corresponds to the proportion of Ireland's liquid market based on domestic milk intake in 2009 (National Milk Agency, 2010), and divided by 12. Butter, cheese and casein were assumed to be constrained by processing capacity which was computed as national product-line average where total output at national level (IDB, 2010) was divided by the number of plants manufacturing these items (derived from DAFF, 2010b), and subsequently divided by 12. WheyP was treated as a by-product of cheese and casein output and thus limited by the volume of whey resulting from cheese and casein manufacture. Monthly WMP capacity was calculated as national WMP output

Table 3: Product composition

Output	SolidsO[a] kg solids/tonne of output					
	FAT	**PRO**	**LAC**	**NFS**	**CPRO**	**WPRO**
Liquid milk[b]	35.0			79.0		
Butter[c]	800.0	4.0	3.0			
Cheddar[c]	320.0		1.9		260.0	
Casein[c]	9.0		1.9		900.0	
WMP[c,d]	280.0			630.0		
SMP[c,d]	8.0			875.0		
WheyP[c,e]	13.0		780.0			122.0
Lactose[b]		2.0	946.0			

[a]SolidsO = milk solids levels in output: FAT = fat, PRO = protein, LAC = lactose, NFS = non-fat solids, CPRO = casein protein, WPRO = whey protein.
[b]Breen (2001).
[c]IDB, Dublin, Ireland, personal communication.
[d]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder.
[e]McCance and Widdowson (2002).

divided by the number of WMP-producing plants, and divided by 12. Total output of WMP, SMP and WheyP was capped by drying capacity. Lactose output was restricted by the solids available from the milk pool. All items were allowed to be produced year-round except for cheese: Due to unsatisfactory processability characteristics of some late lactation milk, cheese and its by-product were automatically excluded from the list of product options in months where the raw milk pool's LAC levels fell below 4.3% (Guinee et al., 2007).

Labour capacities

The monthly labour pool from all permanent staff was estimated from Smooth and specified as 11,520 labour hours. For this purpose, the annual labour requirement was divided by 12 and calibrated to identify 72 full-time equivalents per month. One full-time equivalent amounted to 48 work weeks per year at 40 hours per week, equalling 1,920 labour hours per worker per year (Oireachtas, 1997). Smooth was selected for the labour pool estimates as this scenario indicates the work requirement that would be sufficient for processing in a situation with a smooth pattern of milk deliveries. To facilitate additional labour requirements associated with seasonal variation in milk deliveries it was assumed that casual labour (hours) could be hired without restriction.

Validation

Model structure and assumptions were reviewed in two independent face validation exercises by dairy technologists at Teagasc Moorepark, Ireland's national dairy research centre. A plausible imitation of real-world decisions and processes in Irish dairy manufacturing enterprises received particular attention.

Furthermore, processing cost data were validated in a two-stage process. Firstly, preliminary unit variable processing costs for each product were prepared in consultation with Moorepark dairy technologists based on figures from a survey conducted by Breen (2001). Next, dairy co-operative production managers and management accountants were consulted in order to calibrate the cost data for each product. The experts revised the cost estimates to reach a consensus on a representative set of unit-based costs for each product in and iterative process.

4. Scenarios

Three scenarios representing different milk intake profiles were run for a 12-month period from the perspective of a single dairy processing enterprise (Figure 2). In order to identify seasonality-related effects resulting from shifts in the distribution of raw milk intake occurring within one plant, the same plant equipment and labour pool were imposed on all 3 scenarios. Whereas the Baseline scenario reflects a distribution of milk intake typical for the average processor operating in Ireland in 2009, the other scenarios aim at illustrating how a smoother (Smooth scenario) or a more seasonal (Seasonal scenario) pattern affect the processing enterprise's performance. To ensure comparability of the different situations examined, only selected key variables as outlined below were altered from Baseline.

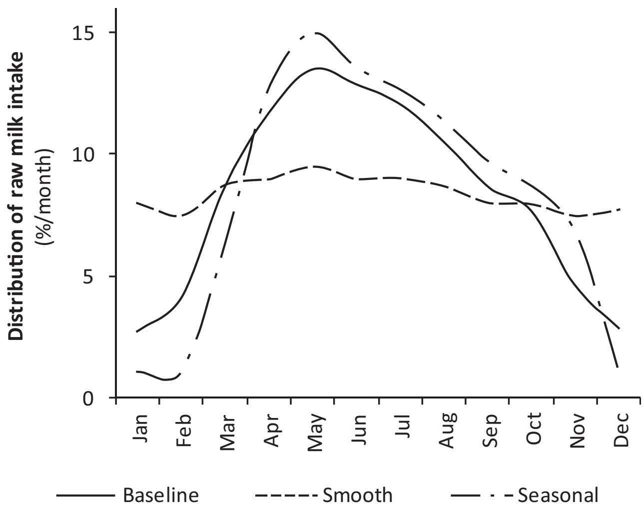

Figure 2: Distribution of raw milk intake

Baseline

The Baseline scenario was characterised by an intake pattern derived from the monthly distribution of domestic milk intake at national level (derived from CSO, 2011) with a PT ratio of 4.9:1 and an annual intake of 273,746 tonnes.

Smooth

In the Smooth scenario, monthly milk intake varied little (PT ratio: 1.3:1) due to an all year round even calving pattern, allowing for a better utilisation of equipment and workforce in the trough months while deteriorating capacity utilisation in the peak months.

Seasonal

It has been suggested that Irish dairy farmers should aspire a more compact spring calving pattern, thus reducing feed costs and improving competitiveness (Teagasc, 2009). An intensified calving compaction could result in a more extreme milk supply curve to dairy processors. In Seasonal, milk intake increased more steeply than in Baseline while total milk intake and processing capacities remained unchanged. A sufficient amount of raw milk was available to secure year-round liquid milk production; however, limited milk volumes permitted only minimal production of manufactured dairy products in the trough period (December, January and February).

5. Results

Product mix and processing capacity utilisation

Liquid milk was identified by the model as the most financially rewarding product, followed by casein, cheddar cheese, WMP and SMP, respectively. Butter and lactose came into the solution with the manufacture of the aforementioned products. WheyP varied proportionally as a by-product of casein and cheese output. The full product portfolio was manufactured in the months of higher intake, i.e. in two months in Seasonal and one month in Baseline whereas Smooth engaged in the manufacture of all products but SMP in three months. Annual results show that the seasonal scenarios included a higher tonnage of milk powders (Seasonal: 1,886 tonnes; Baseline: 1,422 tonnes) as opposed to Smooth (83 tonnes), which manufactured the largest quantity of the most profitable manufactured product casein (Table 4).

Liquid milk capacity was entirely filled in all scenarios and casein capacity was exploited at 75% (Seasonal) and above (Baseline: 87%; Smooth: 100%). Other than that, capacity utilisation was poor in the trough periods; much less output was manufactured in Baseline's and Seasonal's trough periods as opposed to Smooth. It is also shown that during the peak month of May, Seasonal required 1.9 times the dryer capacity as compared to Smooth (Table 5). Overall, the plant modelled in Smooth would manage with considerably smaller capacities due to the absence of milk supply peaks (see discussion).

Milk solids marginal values and marginal producer milk price

The *SolidsMV* changed throughout the year due to variations in the product mix and raw milk composition. The minimum to maximum ranges for *FATMV* and *LACMV* were similar in Baseline (FAT: €2.85-€2.99; LAC: €0.23-€0.36), Seasonal (FAT: €2.86-€2.99; LAC: €0.23-€0.36) and Smooth (FAT: €2.84-€3.02; LAC: €0.24-€0.36). Larger variations in the *PROMV* were apparent when juxtaposing the seasonal scenarios and Smooth. Compared to Smooth (€4.47-€5.08), the difference between the lowest and the highest value was larger in Baseline (€4.21-€5.72) and Seasonal (€4.24-€5.73). This reflects that throughout the year, there were periods in the seasonal scenarios in which the capacities were less utilised (i.e. higher MV) or better utilised (i.e. lower MV) (Table 6).

Smooth achieved an annual weighted average *MPMP* of €c24.71 followed by €c24.15 in Baseline and €c23.33 in Seasonal. Historical data on the manufacturing milk price indicates similar values of €c28.15 (3-year weighted average 2008 to 2010) or €c22.44 (weighted average 2009) per kg (CSO, 2011). The *MPMP* is broken down into four elements, i.e. a reward for the FAT, PRO and LAC components and a volume deduction. In all scenarios, the PRO element fluctuated more than the FAT and LAC elements. Also, the PRO element was approx. 60% higher in value than the FAT element (weighted average), and the LAC element was negligibly small. *VolCharge* (€c/kg raw milk) was lowest in Smooth (€c3.47), higher in Baseline (€c3.73) and highest in Seasonal (€c3.85) (Table 6). Furthermore, the seasonal scenarios displayed a *MPMP* curve countercyclical to the milk intake pattern, i.e. lower prices in peak months and higher prices in trough months. There was notably less *MPMP* variation in Smooth than in the seasonal scenarios (Figure 3).

Financial performance and seasonality costs

Smooth (€103.4m) achieved the highest annual *SalesRev*, followed by Baseline (€102.2m) and Seasonal (€101.7m). Thus, *SalesRev* increased with a smoother distribution of milk intake, but differed only to a modest extent. The highest annual *Surplus* was realised in Smooth (€78.0m), followed by Baseline (€75.5m) and Seasonal (€74.2m). Logically, the surplus per unit of raw milk (€c/kg) was higher in Smooth (€c28.48) as opposed to the seasonal scenarios (Baseline: €c27.56; Seasonal: €c27.11). *FC* amounted to €7.0m in Smooth, followed by €7.5m in Baseline and €7.8m in Seasonal. The per kg of raw milk equivalent was €c2.57 (Smooth), €c2.75 (Baseline) and €c2.85 (Seasonal) (Table 6).

The model results show that across all scenarios, the costs in question correlated positively with an increasing degree of milk intake seasonality (Tables 6 and 7).

Table 6 documents that *CollHandVC* amounted to €2.47m in Smooth, €2.66m in Baseline and €2.74m in Seasonal. *ProcessVC* totalled €15.87m in Baseline and were similar in Smooth (€15.81m) and Seasonal (€16.03m). The model reported total labour costs (*LabourVC* + *LabourFC*) of €2.97m for Smooth, followed by €3.31m for Baseline and €3.43m for

Table 4: Product mix by month

Output[a] tonnes	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Baseline													
Liquid milk	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	33,972
Butter	255	405	611	569	590	534	567	571	570	580	524	285	6,061
Cheddar			745	1,489	1,875	1,847	1,624	1,529	1,100	801			11,010
Casein	140	234	357	357	357	357	357	357	357	357	329	167	3,726
WMP			108	298	298	298	298						1,300
SMP					122								122
WheyP	226	378	927	1,275	1,455	1,442	1,338	1,294	1,093	953	533	270	11,184
Lactose	40	97	221	272	297	281	246	181	93	73	25	15	1,841
Dry	226	378	1,035	1,573	1,875	1,740	1,636	1,294	1,093	953	533	270	12,606
Smooth													
Liquid milk	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	33,972
Butter	634	619	615	564	534	540	565	572	574	593	610	628	7,048
Cheddar	684	527	855	1,033	1,203	1,054	1,039	962	826	795	628	650	10,256
Casein	357	357	357	357	357	357	357	357	357	357	357	357	4,284
WMP			69	7	7								83
SMP													
WheyP	898	825	978	1,061	1,141	1,071	1,064	1,028	964	950	872	882	11,734
Lactose	171	166	180	168	171	166	174	155	124	129	126	151	1,881
Dry	898	825	1,047	1,068	1,148	1,071	1,064	1,028	964	950	872	882	11,817
Seasonal													
Liquid milk	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	2,831	33,972
Butter	32	19	587	587	751	588	567	574	576	591	595	32	5,499
Cheddar			124	1,768	1,875	1,875	1,767	1,747	1,388	1,092	617		12,253
Casein	6	<1	357	357	357	357	357	357	357	357	357	5	3,224
WMP			108	298	298	298	298						1,300
SMP					464	122							586
WheyP	9	<1	636	1,405	1,455	1,455	1,405	1,395	1,227	1,089	867	9	10,952
Lactose	1	<1	143	296	313	306	275	213	122	89	36	<1	1,794
Dry	9	<1	744	1,703	2,217	1,875	1,703	1,395	1,227	1,089	867	9	12,838

[a]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder, Dry = dryer output; results rounded to the nearest whole number.

Table 5: Capacity utilisation – minimum, maximum, average

Cap.Ut.[a] % Output[b]	Baseline			Smooth			Seasonal		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Liquid milk	100	100	100	100	100	100	100	100	100
Butter	24	58	48	51	60	56	2	71	44
Cheddar	0	100	49	28	64	46	0	100	54
Casein	39	100	87	100	100	100	0	100	75
WMP	0	100	36	0	23	2	0	100	36
Dry	10	83	47	37	51	44	0	99	48

[a]Cap.Ut. = capacity utilisation; Min = minimum, trough month; Max = maximum, peak month; Scenario: Min/Max of raw milk intake = Baseline: Jan/May, Smooth: Nov/May, Seasonal: Dec/May; Avg = Output p.a. / (Output capacity p.m. × 12).
[b]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder, Dry = drying capacity; SMP is limited by the dryer capacity, WheyP is limited by the dryer capacity, cheddar and casein output; Lactose is limited by its availability from the raw milk pool.

Seasonal. Not only did a more seasonal milk intake curve result in higher total labour costs, but also in a higher proportion of labour costs incurred by seasonal workforce (*LabourVC*; Seasonal: 15.4%; Baseline: 12.4%; Smooth: 2.3%). Analogously, stock holding costs (*StorageVC* + *StockFC*) in Smooth (€0.20m) were considerably lower than in Baseline (€0.91m) and Seasonal (€1.27m). S*tockFC* accounted for the larger proportion of stock holding costs (Seasonal: 71.0%; Baseline: 71.1%; Smooth: 69.7%).

Table 7 shows how Baseline and Seasonal results deviate from Smooth. *SeasonActivC* amounted to €2.02m in Seasonal and €1.32 in Baseline and are broken down into *CollHandVC*, *ProcessVC*, stock holding costs and total labour costs. *CollHandVC* in Smooth undercut Baseline by 8.0% (−€0.20m) and Seasonal by 11.1% (−€0.27m). Smooth's *ProcessVC* varied very little compared to Baseline (−0.4%) and Seasonal (−1.4%). Stock holding costs in Smooth were 78.3% (−€0.72m) below those in Baseline and 84.3% below those in Seasonal (−€1.07m). Finally, Smooth's total labour costs fell short of Baseline by 10.4% and of Seasonal by 13.5%.

In total, Smooth surmounted the *Surplus* realised in Baseline by €2.51m and in Seasonal by €3.75m (*SeasonalityC*), which equals *SeasonMixC* of €1.19m in Baseline and €1.73m in Seasonal.

Discussion

Financial performance and seasonality costs

The *SeasonalityC* arising to a dairy processing business were subdivided in this paper into costs arising from (a) activities related to the processor's production plan, which include raw milk collection and handling, processing, stock holding and labour, and (b) a product mix which is less profitable than the Smooth scenario's mix. A higher degree of milk intake seasonality resulted in higher *SeasonalityC* and a lower *Surplus*.

The *Surplus* figure represents the amount available for covering the milk payments and the retained processor profit. Smooth registered the highest *Surplus* followed by Baseline and Seasonal, respectively. The main reason for these variations is a different distribution of milk intake caused by the underlying calving pattern which determines product mix choices and the *SeasonalityC*. However, the financial net benefit of smoothing out the milk intake curve was relatively minor: *SeasonalityC* resulted in €2.5m less for Baseline and €3.8m less for Seasonal when compared to Smooth which registered a *Surplus* of €78.0m. In practice, switching to an even supply would involve milk price adjustments to incentivise non-seasonal production by which the reported benefits may quickly dissipate.

Regarding the *SeasonActivC*, *CollHandVC* were lower in Smooth compared to the seasonal situations as the fleet was used more efficiently off the peak periods, which is reflected in the lower raw milk collection and transport costs. Despite *ProcessVC* similar across the scenarios, underutilisation of processing capacities in the seasonal situations were apparent; this is explained by low milk supplies in the winter months. Total labour costs (*LabourVC*, *LabourFC*) were also comparable, whereas abundant milk supplies in the summer months required the processor to hire casual workforce (*LabourVC*). Extra stock holding costs (*StorageVC*, *StockFC*) were caused by the disparity between production (*Output*) and sales (*Sales*) levels in the peak season caused by larger output quantities to be put on stock (*Stock*). The stock holding costs accounted for the second largest item in the *SeasonalityC* calculation. Overall, however, the variation of the *SeasonActivC* across the scenarios was modest and the advantage of Smooth over the other scenarios (−€1.3m relative to Baseline; −€2.0m relative to Seasonal) is not likely to justify a massive restructuring of the entire industry. *SeasonMixC* emerged as the single largest seasonality-related cost. The *SeasonMixC* could be reduced by aiming at a product mix more similar to the Smooth scenario's production plan but this was not possible due to the seasonal distribution of raw milk intake. Implications of potential product mix and plant capacities changes are addressed below. Overall, whereas the *SeasonalityC* are small in a quota-constrained market, it should be noted that they may become a rather critical issue in a liberalised milk market which may give impetus for a strategy change towards a smoother milk intake curve.

Processing capacities and fixed costs

A processing business aligned to a smooth milk intake curve generally requires less processing capacity and

Table 6: Financial results summary

Results	Variable		Baseline	Smooth	Seasonal
Annual totals, €'000					
Sales revenue	*SalesRev*	Year	102,200	103,389	101,664
Variable costs – Output			−16,547	−15,937	−16,922
of which Processing	*ProcessVC*	Year	−15,872	−15,809	−16,025
of which Storage	*StorageVC*	Year	−264	−61	−367
of which Labour	*LabourVC*	Year	−411	−67	−530
Product gross margin	*Margin*	Year	85,653	87,452	84,742
Variable costs – Input					
Raw milk coll. and hand.	*CollHandVC*	Year	−2,664	−2,467	−2,741
Fixed costs	*FC*	Year	−7,541	−7,029	−7,791
of which Stock	*StockFC*	Year	−650	−138	−900
of which Labour	*LabourFC*	Year	−2,903	−2,903	−2,903
of which Overheads	*OverhFC*	Year	−3,988	−3,988	−3,988
Processor gross surplus	*Surplus*	Year	75,448	77,956	74,210
Marginal raw milk costs	*MPMP* × *Input*	Year	−66,118	−67,656	−63,852
Per unit, €c/kg raw milk					
Fixed costs	*FC*	Year	−2.75	−2.57	−2.85
Gross surplus	*Surplus*	Year, W.avg.[a]	27.56	28.48	27.11
Marginal producer milk price	*MPMP*[a]	Year, W.avg.[a]	24.15	24.71	23.33
Marginal producer milk price	*MPMP*[a]	Min-Max[a]	21.02–31.32	23.60–26.24	20.80–31.75
of which Volume charge	*VolCharge*	Year	−3.73	−3.47	−3.85
Per unit, €/kg milk solid					
Marginal milk solids values	*SolidsMV*				
Fat	*FATMV*	Min-Max[a]	2.85–2.99	2.84–3.02	2.86–2.99
Protein	*PROMV*	Min-Max[a]	4.21–5.72	4.47–5.08	4.24–5.73
Lactose	*LACMV*	Min-Max[a]	0.23–0.36	0.24–0.36	0.23–0.36

[a]W.avg. = weighted average, Min = minimum, Max = maximum; results rounded to nearest whole numbers.

Table 7: Seasonality costs

Annual results, €'000	Variable	Baseline[a]	Seasonal[b]
Activity costs	*SeasonActivC*	1,319	2,021
of which Raw milk collection and handling[a]	*CollHandVC*	197	274
of which Processing	*ProcessVC*	63	216
of which Stock holding	*StorageVC* + *StockFC*	715	1,068
of which Labour	*LabourVC* + *LabourFC*	344	463
Product mix costs	*SeasonMixC*	1,189	1,725
Seasonality costs, total	*SeasonalityC*	2,508	3,746

[a]Seasonality costs of Baseline = Baseline results – Smooth results
[b]Seasonality costs of Seasonal = Seasonal results – Smooth results

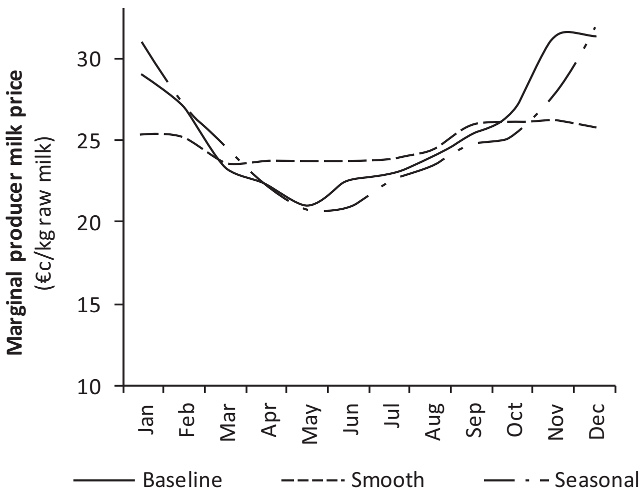

Figure 3: Effects of production seasonality on the marginal producer milk price

thus has lower overhead costs due to the absence of major milk production peaks. In the case of Smooth, dryer capacity could nearly be halved, butter (–40%) and cheddar cheese (–36%) capacities could also be reduced substantially. However, the Smooth scenario presented in this paper examined a plant which converted from operating in a seasonal milk market to a flat milk intake curve. Thus it was assumed that the business observed in Smooth had the same plant structure and fixed costs as Baseline. The fixed costs imposed on Smooth were seen as 'sunk costs' which means that the overheads incurred by the plant in Baseline were irreversible, so that no fixed costs savings were realised when switching to a flat intake curve.

Nonetheless, there is scope to improve processing capacity utilisation and financial performance when smoothing out the milk supply curve, i.e. when simultaneously increasing annual milk intake volume. Thus, additional raw milk is processed in what previously qualified as trough periods, and *FC* are spread over a larger milk pool which effectively decreases the *VolCharge* and increases the *MPMP* per kg of raw milk. The removal of the milk quota regime effective from 2015 could facilitate such a strategic new positioning: By 2020, Irish milk producers are expected to increase milk production between 30% (Keane, 2010) and 50% (DAFF, 2010a), provided economic and climatic circumstances are favourable. In this context, processors must decide whether to further support a seasonal milk production by building additional capacities for the peak period or whether present capacities could be used more efficiently by means of smoothing out the milk intake pattern.

A move to less seasonal milk production systems will involve higher costs for producers which must be set against the potential benefits that will accrue to processors. On the other hand, continuation of seasonal production coupled with expansion in milk output will necessitate additional investment in peak processing capacity, the cost of which will be passed back to producers through lower milk prices. This raises important questions about whether these costs will be shared by all milk producers or only by those who actually expand their peak season milk production. Further considerations about investment into processing equipment concern product mix decisions, e.g. if the portfolio were to be changed from focusing on milk powder output towards more profitable or value-added products. Smooth focused on manufacturing the more profitable products throughout the year and consequently differed from the seasonal scenarios with respect to the product portfolio. Smooth showed a far higher casein output (+33%) than Seasonal and little milk powder output. However, the market capacity for the products to be introduced may be limited. Similarly, where the markets for the presently produced goods are saturated, processors need to seek sales opportunities for additional output resulting from an increased raw milk volume in a liberalised market. Consequently, the marketability of the targeted products in existing geographical markets, the requirement for entering new markets, and the costs entailed by finding or creating additional demand would need to be taken into consideration when opting for product mix changes and output increases.

Milk solids marginal values and marginal producer milk price

Marginal values are affected by the production and marketing capacities relative to the availability of raw materials. In the case of a milk processing plant, it is optimal for the processor to first allocate its raw materials (i.e. milk solids) to the most profitable product until the capacity or market constraint for that product is reached. Milk solids are then allocated to the next most profitable product and so on until the milk supply is exhausted.

Consequently, in a month of high milk supply, capacities for the higher-margin products are exhausted and milk must be allocated to lower-margin products, thereby driving down the shadow price (marginal value) for extra units of purchased milk. However, if the processor has a small volume of milk supply relative to a large processing capacity for a high margin product, both *SolidsMV* and *MPMP* in that month will be high if the processor has scope to allocate additional milk to the high margin product. Thus in a market with seasonal milk supply, *SolidsMV* and *MPMP* are likely to be higher in trough months and lower in peak months of supply. This was evident in the model results where the monthly *MPMP* curve was more stable in the Smooth scenario than in Baseline or Seasonal. The weighted average annual *MPMP* per kg raw milk was highest in Smooth (€c24.71), followed by Baseline (€c24.15) and it was lowest in Seasonal (€c23.38). These differences reflect the fact that in the Baseline and Seasonal scenarios a greater proportion of raw milk was processed into lower margin milk powders (SMP, WMP) and it was these commodities that effectively set the marginal milk price in peak months of raw milk supply. *MPMP* was further supressed in the Baseline and Seasonal scenarios due to seasonality elevating key processing costs in areas such as product storage, especially interest on working capital, and labour utilisation.

Nevertheless the model results suggest that the benefits to Irish producers in terms of higher *MPMP* per kg of raw milk from switching to a smoother production profile are relatively modest (€c0.56 relative to Baseline; €c1.33 relative to Seasonal). This is especially relevant since the potential producer price enhancement must be weighed against the extra production costs, higher feed costs in particular (Dillon et al., 2008), of non-seasonal dairy systems.

6. Conclusions

This paper examined a plant operating three differing intake patterns in a milk-quota constrained environment. However, Irish milk producers are expected to significantly increase supply post milk quota abolition in 2015, which in turn requires a strategy for processors dealing with this larger milk pool in a liberalised market. This strategy could encourage, for instance, a smoother milk supply curve or an altered structure of the processing sector. In this context, future research could address the key questions of (a) whether the plant capacities available at present suffice to cover the extra raw milk volume provided the national milk supply curve is flattened or (b) whether substantial investment should be made so as to be able to maintain the traditional pasture-based dairy production which is seasonal in nature. Alternatively, new markets could be targeted which would entail considerable expenses for establishing logistics, business relations, a marketing strategy etc. Operating a seasonal dairy industry is a strategic choice which implies servicing different market segments (i.e. commodities) and being exposed to other risks (i.e. price fluctuations on international markets).

In a quota-constrained environment, the model results suggest that efforts to aggressively reduce seasonality are unlikely to significantly enhance the profitability of the Irish dairy industry. Specifically, the financial gains to the processor from pursuing non-seasonal production appear to be relatively modest since the capacities required for current production peaks are in place. Capacity-related sunk costs such as depreciation cannot be reduced through smoothing production. Moreover, the farm-level production costs (esp. concentrate feed) of switching to year-round dairying are likely to be substantial necessitating considerable milk price premiums to encourage greater off-peak production (Davis and Kirk, 1985).

An important caveat is that the above conclusions are based on the current quota constrained environment and with the proposed removal of milk quotas the optimum strategy for processors may change. The industry will need to decide if it is better to incur investment costs for additional peak processing capacity or to incentivise less seasonal production to handle extra supplies through better year-round utilisation of existing plant. This is a crucial strategic decision for Irish milk processors which is being analysed in an extension of the present study.

It has been demonstrated in this paper that the multi-period optimisation model as discussed above proves to be a useful tool for analysing the effects of seasonal milk production at processor level especially with respect to financial performance, product mix, capacity utilisation and operational aspects of seasonality, such as product storage and labour utilisation. It is proposed that a natural extension to the work reported in this paper would be an integrated producer-processor model providing a more holistic industry-level perspective. An integrated approach would allow for a more detailed examination of potential strategies to dampen production seasonality such as seasonal supply contracts and milk pricing incentives. Such an approach would necessarily estimate the likely trade-offs between farm-level production costs versus processor benefits arising from improved market returns and reduced seasonality costs. The objective should be to identify strategies that sustainably enhance the financial performance of the dairy industry as a whole.

About the authors

Karin E. Heinschink (karin.heinschink@gmail.com) studied International Business Administration at the Vienna University of Economics and Business Administration in Austria. Her master's thesis examined "The production of cattle and cattle meat in Austria and the USA" (2008). Today she works as a PhD student at University College Dublin, Ireland under the supervision of Dr. Michael T. Wallace in the field of Agricultural Economics. Her principal research interests include the production and processing of livestock and its products as well as mathematical modelling.

Dr. Laurence Shalloo is a senior research officer at the Animal & Grassland Research and Innovation Centre, Teagasc, Moorepark, Fermoy, Co. Cork, Ireland. His research interests include farm systems and milk processing sector modelling.

Dr Michael T. Wallace is a lecturer in agricultural economics at University College Dublin. He completed his PhD at Queen's University of Belfast on the use of multiple criteria decision making models in agricultural management. He currently teaches in the areas of farm business management, production economics, and business modelling. His principal research interests are in the application of mathematical modelling techniques to the study of agricultural systems and business decision making.

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