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Seasonality in the Irish dairy processing industry

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Abstract

The dairy landscape in the Republic of Ireland is characterized by pastoral spring-calving systems and a bell-shaped milk production curve. This seasonality at producer level initiates various implications at processor level, such as poor utilization of plant capacity off-peak season, a requirement for seasonal labour management and limited product options in autumn and winter months due to the properties of late-lactation milk. An optimization model was developed to analyze the impact of production seasonality and quota removal on the Irish dairy processing industry in terms of maximum processor gross surplus, the optimum product mix and the marginal values of the milk solids fat, protein and lactose. Processor gross surplus was specified as a function of product sales revenue, less variable costs of collecting and processing raw milk and general overhead (fixed) costs. 5 scenarios with differing milk intake curves were examined whereby a flatter intake curve incurred less monthly variation in the marginal producer milk price, capacity utilization and product mix as well as a higher surplus as compared to more seasonal patterns. However, an isolated consideration of financial indicators at processor level disregards key characteristics of Irish grass-based seasonal milk production and producer-processor interdependencies. It was therefore concluded that a broader modelling approach integrating both the producer and the processor perspectives is desirable for more holistic analysis of sector-wide implications.

Key words: Dairy processing; seasonality; milk quota abolition; processor profit; product mix.

1. Introduction

Seasonality. In pastoral milk production systems, the dairy herd's calving dates are matched with the grass-growing season's start in order to maximize the intake of cost-efficient grazed forage, effectively resulting in a seasonal milk production pattern. The producer benefits from reduced feed cost and thus lower production cost per kg of milk, but is vulnerable to adverse climatic conditions which may necessitate diet supplementation by means of more expensive concentrates beyond the housing period. Further consequences relate to replacement decisions, the size of housing facilities and annual distribution of workload and income. Seasonal supply at producer level initiates a variety of challenges in dairy processing and auxiliary activities, such as transport and storage. Implications off peak season include persistent plant and labour capacity underutilization, possibly requiring closing down plants for a part of the year, as well as higher raw milk collection and product storage cost (Prospectus, 2003, Hennessy and Roosen, 2003, Downey and Doyle, 2007). Where output capacities of some, frequently more lucrative, products are fully exploited during peak months due to the disproportionally high milk intake, milk surpluses need to be manufactured into less profitable commodities, such as powders or butter, or sold on. In addition, milk composition changes in the course of lactation; the suitability of late-lactation milk for various products, including milk powders, butter and cheese, is limited with respect to processability, storability and desired product properties (Guinee et al., 2007, Downey and Doyle, 2007, Phelan et al., 1982).

Economic sustainability. The economic sustainability of seasonality in dairy markets has been studied (Downey and Doyle, 2007, 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 utilization 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 cost of raw milk.

Ireland's dairy landscape. The Irish dairy industry is shaped by pastoral milk production systems, resulting in a seasonal intake pattern at processor level. Comparing the annual distribution of cow's milk collected in 2009 identifies Ireland's unique position in the EU: Despite a gradual decline during the last decade, Ireland was the only member state with an average peak-to-trough ratio (**PT ratio**) as high as 4.9:1. Lithuania registered the second highest value in the order of 1.8:1, followed by Latvia (1.7:1), Romania (1.5:1) and Bulgaria (1.4:1). The vast majority, viz. 21 states ranged from 1.1:1 to 1.3:1 (EC, 2010b).

In 2009, 18 processing enterprises (derived from DAFF, 2010) purchased approx. 5.3m tons of raw milk, of which 94% were produced domestically (CSO, 2010). The national product mix consisted mainly of liquid milk (509,600 tons) (CSO, 2010), cheese (157,500 tons), butter (126,000 tons), skim milk powder (**SMP**) (113,000 tons), chocolate crumb (40,500 tons), proteins (30,000 tons) and whole milk powder (**WMP**) (25,000 tons) (IDB, 2010). Dairy exports accounted for €2.7m, or 30% of agri-food and drinks exports, with the UK and continental EU as the most important destinations. The principal dairy commodities marketed abroad were infant foods (23.3% of dairy exports value), cheese (22.9%), butter (13.7%), casein (9.9%) and milk powder (9.9%) (DAFF, 2009). In 2008, an estimated 5,000 persons were employed in the dairy processing sector (CSO, 2010).

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 production quota post 2014/15 and prices are assumed to settle closer to world market prices (O'Connor et al., 2008). In this context, Ireland has been recommended to revisit matters such as the milk producers' cost-effectiveness, scale, technologies applied, environmental impact, related government policies or the structure of the processing sector (Dillon et al., 2008). The model presented in this paper seeks to provide support for the decision-making on suitable strategies for the Irish dairy processing sector in a changing market environment.

Optimization. The usefulness of optimization models to problems in the agro-food industry has been widely acknowledged. Producer-level optimization models have been employed for addressing, inter alia, herd management decisions, such as type of cattle breed, breeding and replacement activities, feeding regime as well as milk yield and milk composition (e.g. DeLorenzo et al., 1992, Wang et al., 2000, De Vries, 2004). At processor-level, optimization techniques have been used for analyzing milk pricing mechanisms, the value of milk components and product mix. Bangstra et al. (1988) argued that, except for the case of liquid milk, the value of raw milk is reduced by the water contained therein. Raw milk value can be increased by biological concentration at producer level (e.g. achieved by selective breeding) or by mechanical concentration (e.g. ultrafiltration) at processor level. The cost of removing the liquid carrier when processing raw milk was modelled for a cheese plant and a plant producing butter and non-fat dairy products. Breen (2001) developed a model for analyzing the merits of a multiple component pricing regime for Irish dairy processing businesses. Milk pricing was found more equitable and transparent when calculated on the basis of milk constituents. It was also found that multiple-component pricing assists in harmonizing the producer's and the processor's interest, and that the value of milk varies depending on the product mix. Other models examine effects of one agent's behaviour on other product life cycle stages or agents. Killen and Keane (1978) optimized the distribution of calving dates required for meeting the year-round demand for dairy products at minimized milk production costs. Davis and Kirk (1985) analyzed the economic aspects of changing seasonal milk production patterns in Northern Ireland by shifting a 10% proportion of peak milk supply to the trough period. Like Keane (2010), 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 cost for the entire system. For example, a flatter milk intake curve may improve the processor's capacity utilization 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.

Objectives. The objective of this paper is to present a milk processing optimization model which maximizes a dairy processor's annual profit generated in operating various milk intake profiles. Scenario analysis gives the opportunity to evaluate the impact of policy changes, such as milk quota abolition, or changes in milk production seasonality on processor profitability, product mix, capacity utilization, milk solids values and the marginal producer milk price.

2. Method

Mathematical models, such as optimization models, are a simplified representation of a real-world situation which seeks to analyze complex systems (Hazell and Norton, 1986). In optimization models, a set of activities, related resource constraints and interdependencies within the system in question are specified. The model solution identifies the minimized or maximized objective value resulting from an optimum combination of activities, as well as the marginal values of the resources constraining the optimal plan. For instance, a list of product options and production capacities is given and, by iteration, the model solves for the surplus-maximizing product mix. Optimization models facilitate a holistic and objective analysis of complex systems and the appraisal of wide ranging business and policy conditions.

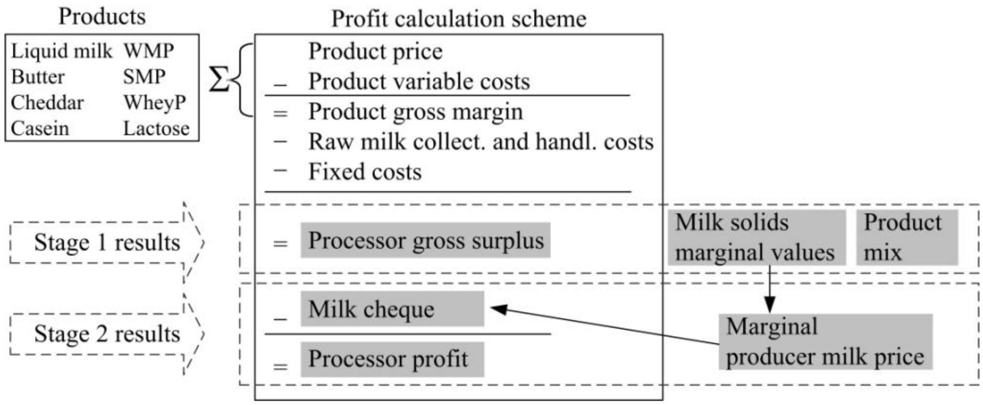
The marginal value, or shadow price, of a limiting resource expresses how much can be spent on an extra unit of the resource without reducing the objective value when other model specifications remain unchanged. In other words, if an agent paid a price higher than the marginal value, they would lose money on each additional unit purchased at that price. Shadow prices are determined 'at the margin' and are therefore affected by the production capacities relative to the availability of raw materials. In the case of a milk processing plant, it is optimal for the processor first to 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 seasonal 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 for extra units of milk supply. However, if the processor has a small volume of milk supply relative to a large processing capacity for a high margin product, the shadow price for milk 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, shadow milk prices are likely to be higher in trough months and lower in peak months of supply. In a non-seasonal situation the shadow milk prices are expected to be relatively constant throughout the year as milk supply does not fluctuate as much relative to the fixed processing capacities.

3. Model

3.1. Model output

A milk processing model was developed for the analysis of profitability based on various milk intake patterns or processing capacities. The model was formulated as a single-criterion, multi-period linear programming problem which identifies the maximum annual processor gross surplus and a corresponding optimum production plan at monthly intervals for an entire year in stage 1 of the modelling process (original model results). A production plan is considered optimal when altering the levels of decision variables (i.e. output quantities) at simultaneously invariant constraints specifications will not increase the processor gross surplus. The model solution further indicates the marginal values of the milk components fat (**FAT**), protein (**PRO**) and lactose (**LAC**), which allows for calculating the marginal producer milk price and the processor profit in the second modelling stage (derived model results). It should be noted that the price payable to the milk producers is covered by the processor gross surplus, as opposed to the processor profit which represents the balance after deducting the payments made for milk supplies (Figure 1). The surplus-maximizing product mix is subject to a set of technical constraints addressing milk solids contents, input volume and output volume (F.2a, F.2b, F.3).

Figure 1: Profit calculation scheme



3.2. *Model structure*

The objective function (F.1) calculates the processor gross surplus as the total gross margin (i.e. price assumed minus variable costs) generated from the production plan, reduced by variable costs arising from raw milk handling activities (i.e. collection, standardization and separation) and fixed costs (e.g. managerial salaries, interest).

$$\text{Max. } Z_t = \Sigma_j (M_{jt} \times y_{jt}) - \Sigma_i (Cv_{it} \times x_{it}) - Cf \quad \text{(F.1)}$$

where t = period; j = output, product type; i = input, raw milk type; Z = total processor gross surplus (€); M_j = product gross margin (€/ton); y_j = product yield (tons); Cv_i = variable input handling cost (€/ton); x_i = input quantity (tons); Cf = annual fixed cost (€). Raw milk type refers to the possibility of introducing milk from different breeds or other milk types of differing compositions (e.g. domestically produced or imported milk).

Product yield is limited by the availability of milk solids and consequently by the quantity and quality of raw milk available for processing. The input-output relationship constraints (F.2a, F.2b) determine that for each unit of milk solid allocated to a product, the amount of solids available from the raw milk pool is reduced by 1 unit:

$$\Sigma_j (Bp_{js} \times y_{jt}) \leq \Sigma_i (A_{its} \times x_{it}) \quad \text{(F.2a)}$$
$$\Sigma_j (Bb_{js} \times y_{jt}) = \Sigma_i (A_{its} \times x_{it}) \quad \text{(F.2b)}$$

where s = type of milk solid; Bp_{js} = milk solids in principal products (kg solids/ton of output); Bb_{js} = milk solids in by-products (kg solids/ton of output); A_{is} = milk solids in raw milk type (kg solids/ton of input). In other words, the resource distributed in the model is not 1 kg of raw milk, but kg of milk solids; hence there is no requirement to specify sequences such as milk intake, pasteurization, standardization, separation, reconstitution etc. Instead, the model is instructed to find the surplus-maximizing product mix for a given monthly quantity of milk solids.

Raw milk composition is determined on a monthly basis. For this purpose, a weighted percentage of solids contents is derived from the calving pattern and lactation curves (Olori et al., 1999) and applied to all milk collected from domestic producers. The rationale is to reflect the variability of raw milk composition which naturally occurs in the course of lactation. This is particularly relevant in an environment characterized by a seasonal milk supply profile as a dairy processor's production options change during the year due to fluctuating quantities of milk components available for processing.

Principal products, which are manufactured independent of each other (F.2a), may generate a by-product consuming solids inapplicable in other principal products. The by-product equation (F.2b) stipulates that such solids must either be fully utilized in the manufacture of by-products intended for selling, or disposed of, irrespective of whether this activity decreases processor surplus.

Furthermore, the model accounts for maximum monthly output levels for individual products as determined by factors such as processing capacity and marketing considerations. (F.3):

$$y_{jt} \leq Dmax_{jt} \qquad \text{(F.3)}$$

where $Dmax_i$ = maximum output volume (tons).

Since the model allocates kg of milk solids rather than kg of raw milk, the marginal producer milk price is not a direct result of the optimization process; it can however be calculated. The marginal producer milk price (€c/kg raw milk) is computed from the marginal values of the milk solids FAT, PRO and LAC (€/kg milk solid) as indicated in the model solution multiplied by the milk solids levels in raw milk (% solids/kg raw milk), and reduced by a volume charge comprising the variable cost of raw milk handling activities (€c/kg raw milk) plus overhead costs (€c/kg raw milk) (F.4):

$$\begin{aligned}\text{Marginal producer milk price} = {} & (\text{FAT value} \times \text{FAT \%}) + (\text{PRO value} \times \text{PRO \%}) \\ & + (\text{LAC value} \times \text{LAC \%}) - \text{Volume charge} \qquad \text{(F.4)}\end{aligned}$$

An example illustrates the breakdown of the marginal producer milk price. If the marginal values of milk solids (€/kg solid) are €2.82 for FAT, €5.52 for PRO and €0.23 for LAC; if the solids levels in raw milk (% solids/kg raw milk) are 4.1% of FAT, 3.3% of PRO and 4.6% of LAC; and if the volume charge (€c/kg raw milk) consists of raw milk handling cost of €c2.98 and fixed cost of €c1.46, then the shadow milk price amounts to €c26.36.

$$\begin{aligned}\text{Marginal producer milk price} = {} & (2.82 \times 4.1\%) + (5.52 \times 3.3\%) + (0.23 \times 4.6\%) \\ & - (2.98 + 1.46) = \text{€c}26.36 \text{ / kg raw milk} \qquad \text{(Example)}\end{aligned}$$

Finally, processor profit is calculated as processor gross surplus less payments to producers (F.5):

$$\begin{aligned}\text{Processor profit} = {} & \text{Processor gross surplus} - \\ & (\text{Milk pool processed} \times \text{Marginal producer milk price}) \qquad \text{(F.5)}\end{aligned}$$

3.3. Model validation

Model structure and assumptions were reviewed in 2 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.

4. Data

4.1. Plant scale

It was decided to create a synthetic plant which processes the national average of domestic raw milk intake (274,644 tons) while availing of processing capacities which were calculated as product-line averages. In other words, the milk pool was specified as total domestic milk intake divided by the total number of processors, and each product's processing capacity was computed as national output divided by actual number of processors manufacturing the product in question (see scenario description). This approach was chosen to ensure that production capacities would be representative of typical production scales for individual products within the industry. Data was retrieved from a variety of secondary sources for the year 2009 and, where necessary, updated for inflation, adjusted for productivity and reviewed by industry experts (see data validation).

4.2. Raw milk

The monthly milk volume available for processing was calculated as creamery domestic milk intake at national level (CSO, 2010) divided by the number of processors. 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 weighted average solids levels were automatically adjusted as soon as an the monthly distribution of calvings changed. A standard charge of €29.81 per ton of raw milk was assigned for collection, separation and assembly (Breen, 2001, updated for inflation via CSO, 2010).

4.3. Milk solids

The milk solids types considered in the milk pool and products were fat (**FAT**), protein (**PRO**), lactose (**LAC**) as well as non-fat solids (**NFS**) (i.e. PRO plus LAC), casein protein (**CPRO**) and whey protein (**WPRO**). The item NFS was introduced to allow for flexibility in composition where FAT levels are standardized while PRO and LAC levels vary in line with raw milk composition (see below: 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).

4.4. Products

A catalogue of 8 product options was specified, including all those which are particularly important in Ireland's national product mix: liquid milk, butter, cheddar cheese, casein, whole milk powder (**WMP**), skim milk powder (**SMP**), whey powder (**WheyP**) and lactose (Table 1). 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 standardized 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 standardized 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 utilize the CPRO component of milk protein only; the remaining WPRO goes into whey, which is subsequently manufactured into the by-product WheyP (Southward, 1998).

Table 1. Product composition

Milk solids[1], kg solids/ton of product	FAT	PRO	LAC	NFS	CPRO	WPRO
Liquid milk[3]	35.0			79.0		
Butter[4]	800.0	4.0	3.0			
Cheddar[4]	320.0		1.9		260.0	
Casein[4]	9.0		1.9		900.0	
WMP[2,4]	280.0			630.0		
SMP[2,4]	8.0			875.0		
WheyP[2,5]	13.0		780.0			122.0
Lactose[3]		2.0	946.0			

[1]FAT = fat, PRO = protein, LAC = lactose, NFS = non-fat solids, CPRO = casein protein, WPRO = whey protein.
[2]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder.
[3]Breen (2001).
[4]IDB, Dublin, Ireland, personal communication.
[5]McCance and Widdowson (2002).

4.5. Financial data

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

Product variable costs comprised fuel and power, direct labour, added ingredients, packaging, transport, storage, losses, effluent, interest and other direct expenses. Historical cost data (Breen, 2001) was updated for inflation and where applicable adjusted for productivity increases (EC, 2010b, IPCC reports, processor annual reports, CSO, 2010) to 2009 level and validated via industry consultation (Table 2).

Gross margin per ton of product as applied in the objective function was calculated as price less variable costs (Table 2).

Annual fixed costs were estimated to be €c1.46 per kg of raw milk processed. This figure includes depreciation, insurance, rent, R&D, interest, management, quality control and central IT and administration (industry consultation).

4.6. Technical constraints

A monthly upper limit was determined both for input and selected outputs. The volume of raw milk to be processed was capped by the milk pool available. Liquid milk output was determined not to exceed 9.6% of the annual milk pool pre-quota abolition, which corresponds to the proportion of Ireland’s liquid market based on domestic milk intake (NMA, 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 whereas total output at national level (IDB, 2010) was

Table 2. Product prices, variable costs and gross margins

Product	Price[2], €/ton	Variable cost[7], €/ton	Gross margin[8], €/ton
Liquid milk	627[3]	224	403
Butter	2,620[4]	344	2,276
Cheddar	2,759[4]	351	2,408
Casein	6,480[5]	438	6,042
WMP[1]	2,471[6]	364	2,107
SMP[1]	1,973[4]	296	1,677
WheyP[1]	535[6]	295	241
Lactose	577[5]	349	228

[1]WMP = whole milk powder, SMP = skim milk powder, WheyP = whey powder.
[2]Applies to Baseline, Smooth, Seasonal, NoQuota-Invest-BP and NoQuota-Smooth-BP.
[3]Derived from Young (2009) and NMA (2010)/CSO (2010).
[4]Prices for the Ireland, average Jan 2008 to Dec 2010 (EC, 2010a).
[5]Prices for the USA, average Jan 2008 to Dec 2010 (Productschap Zuivel, 2010).
[6]Prices for the Netherlands, average Jan 2008 to Dec 2010 (Productschap Zuivel, 2010).
[7]Breen (2001), adjusted for inflation and productivity increases (EC, 2010b, IPCC reports, processor annual reports, CSO, 2010) and validated by industry consultation. Applies to all scenarios.
[8]Gross margin = Price – Variable cost. Applies to Baseline, Smooth, Seasonal, NoQuota-Invest-BP and NoQuota-Smooth-BP.

divided by the number of plants manufacturing these items (derived from DAFF, 2010), 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. WMP capacity was calculated as national WMP output divided by the number of WMP-producing plants, and divided by 12. Total powder output, i.e. WMP, SMP and WheyP was capped by dryer capacity. It was assumed that the dryer operates close to its capacity limits in the peak period of the Baseline scenario, which was selected as maximum dryer capacity for all subsequent scenarios. Lactose output was restricted by the solids levels available from the milk pool. All items were allowed to be produced year-round except for cheese: Due to unsatisfactory processability characteristics of 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). Finally, the plant operated all 12 months of the modelled horizon.

4.7. Data validation

Processing cost data was validated in a 2-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), i.e. they were updated for inflation and productivity increases. Next, dairy co-operative production managers and management accountants were consulted in order to calibrate the cost data for each product. Through an iterative process the experts revised the cost estimates to reach a consensus on a representative set of unit-based costs for each product.

5. Scenarios

5 scenarios representing different milk supply profiles and expansion scenarios were run for a 12-month period from the perspective of a single dairy processing enterprise.

5.1. Quota-constrained scenarios

Baseline. The Baseline scenario was characterized by an intake pattern derived from the monthly distribution of domestic milk intake at national level (Table 3) (CSO, 2010) (with a PT ratio of 4.9:1 and an annual total intake of 274,644 tons. A monthly maximum output quantity was specified for liquid milk (2,831 tons), butter (1,050 tons), cheddar cheese (1,875 tons), casein (357 tons) and WMP (298 tons) (IDB, 2010, derived from CSO, 2010, DAFF, 2010, NMA, 2010). The dryer, which was used in the manufacture of WMP, SMP and WheyP, was assumed to operate somewhat below its limit in the peak month (2,250 tons). Fixed costs amounted to €4.0m per annum. To ensure comparability of the different situations examined, all specifications of the other scenarios were identical to Baseline unless declared separately.

Smooth. In the Smooth scenario, monthly milk intake varied little (PT ratio: 1.3:1) due to an even calving pattern, allowing for a better utilization of equipment and labour force throughout the year (Table 3).

Seasonal. It has been suggested that Irish dairy farmers should aspire a more compact spring calving pattern, thus reducing feed cost and improving competitiveness (Teagasc, 2009). An intensified calving compaction results in a more extreme milk supply curve to dairy processors. In the Seasonal scenario, milk intake increased more steeply than in Baseline (Table 3) while total milk intake and processing capacities remained unchanged. A sufficient amount of raw milk was available to secure year-round liquid milk production. Assuming that the dairy herd was dried off in November, manufacturing plant was closed down in January and December. (The small volume of raw milk exceeding the liquid milk requirements in these months was allowed to be processed nonetheless.)

5.2. NoQuota scenarios

NoQuota-Invest. The abolition of the EU milk quota is expected to result in an expansion of at least 30% in Irish milk production by 2020 provided economic and climatic circumstances are favourable (Keane, 2010). In the NoQuota-Invest scenario the processor's milk volume was specified to expand relative to Baseline to a somewhat lesser extent by 25% to 343,305 tons. The seasonal supply profile was assumed to remain the same as in Baseline (PT ratio of 4.9:1) (Table 3). To accommodate increased intake during peak months, the construction of a milk powder plant considered. Dryer capacity was raised from 2,250 tons to 4,000 tons per month and the marketing capacity of WMP was increased to 372 tons (+25%). Additional fixed costs incurred by the drying plant amounted to €5.94m for the entire investment, resulting in an annual investment cost of €0.99m when allocating the equivalent of 3.5% interest (industry consultation) and 13.2% depreciation (derived from published accounts, average across buildings and machinery depreciation rates) per annum. Including fixed costs of €5.0m, total overhead costs amounted to €5.99m in NoQuota-Invest.

NoQuota-Smooth. Where production is expanded while a seasonal supply pattern is maintained, the processing sector is likely to face capacity shortages during peak months. However, there is scope for accommodating this extra milk volume without further investment into processing capacity, i.e. by smoothing out the milk supply curve. In the NoQuota-Smooth scenario, total milk intake was raised to 343,305 tons and distributed as in Smooth (PT ratio: 1.3:1) (Table 3) while all capacities, except for WMP (372 tons), were retained as in Baseline. Annual fixed costs were €5.0m.

5.3. Sensitivity analysis

The increase in manufactured dairy product supply is likely to result in a reduction in product prices. Since the extent of the price reduction is not easily estimated, a sensitivity analysis was conducted for each NoQuota scenario with respect to product prices. NoQuota-Invest was measured against Baseline and NoQuota-Smooth was benchmarked against Smooth. Firstly, each NoQuota scenario was run at base prices (the prices applied to Baseline and Smooth, which were identical). Then, prices of the manufactured products, i.e. all items except for liquid milk, were reduced uniformly in a series of iterations to identify the percentage reduction that resulted in processor gross surplus falling to the level reported for its reference scenario. This identified the break-even price reduction; the point beyond which further declines in product prices result in processor surplus being below the reference level (i.e. the industry would be worse off despite the increase in milk production). The NoQuota scenarios run at base prices were labelled NoQuota-Invest-BP and NoQuota-Smooth-BP, those run at reduced prices were named NoQuota-Invest-RP and NoQuota-Smooth-RP.

Table 3. Distribution of milk intake by month

Milk intake (%)	Baseline[1], NoQuota-Invest-BP/RP	Smooth, NoQuota-Smooth-BP/RP	Seasonal
Jan	2.7	7.9	1.1
Feb	4.1	7.4	1.1
Mar	8.7	8.7	6.5
Apr	11.7	8.9	12.9
May	13.5	9.5	14.9
Jun	12.9	9.0	13.5
Jul	12.1	9.0	12.6
Aug	10.5	8.6	11.3
Sep	8.7	8.0	9.7
Oct	7.6	7.9	8.7
Nov	4.6	7.4	6.8
Dec	2.8	7.7	1.0
Total	100.0	100.0	100.0

[1]Derived from CSO (2010).

6. Results

6.1. Turnover

Under the fixed milk quota scenarios, Smooth (€103.7m) achieved the highest annual turnover, followed by Baseline (€102.5m) and Seasonal (€101.8m) (Table 4). The NoQuota scenarios should be interpreted separately due to the higher milk volume processed. NoQuota-Smooth-BP generated a turnover of €126.5m and NoQuota-Invest-BP €124.3m. The processor gross surplus fell to the reference level (Smooth and Baseline, respectively) when applying a 15% price cut to the manufactured dairy products, resulting in a turnover of €110.7m in NoQuota-Smooth-RP and €108.9 in NoQuota-Invest-RP (Table 5). Across all scenarios, turnover clearly increased with a smoother distribution of milk intake. Both in the quota-constrained and in the NoQuota-situations, turnover differed only to a minor extent.

6.2. Processor gross surplus

Among the quota scenarios, the highest annual surplus was realized in Smooth (€71.8m), followed by Baseline (€70.7m) and Seasonal (€69.9m). It should be noted that the only reason for these variations is a different distribution of milk intake caused by the underlying calving pattern which determines product mix choices. The model solution suggests that the financial net benefits of smoothing out the milk intake curve is only minor with respect to the surplus (Smooth: +1.7%, Seasonal: -1.1% as compared to Baseline). In practice, switching to an even supply would involve considerable operational costs (e.g. milk price adjustments to incentivise non seasonal production) by which the reported benefits may quickly dissipate (Table 4).

NoQuota-Smooth-BP showed a surplus of €87.8m and NoQuota-Invest-BP was €85.3m. NoQuota-Smooth-RP broke even at €72.0m and NoQuota-Invest-RP realized a smaller surplus of €69.8m, which is due to the lower output price assumptions, the investment-incurred fixed costs and a different product mix (Table 5).

The surplus per unit of raw milk (€c/kg) was higher in the quota-constrained scenarios (Smooth: €c26.15, Baseline €c25.72, Seasonal €c25.45) and the post-quota scenarios at Baseline prices (NoQuota-Smooth-BP: €c25.56, NoQuota-Invest-BP: €c24.83) as opposed to the reduced product price scenarios (NoQuota-Smooth-RP: €c20.97, NoQuota-Invest-RP €c20.33).

Table 4. Annual financial results in the quota-constrained scenarios:
Turnover, surplus, profit, marginal producer milk price and milk solids marginal values

Annual financial results	Baseline	Smooth	Seasonal
Profit calculation, '000 €			
Turnover	102,512	103,696	101,812
Surplus	70,646	71,814	69,893
Milk cheque	-63,338	-63,737	-61,780
Profit	7,308	8,077	8,113
Surplus, €c/kg raw milk	25.72	26.15	25.45
Profit, €c/kg raw milk	2.66	2.94	2.95
Marginal producer milk price, €c/kg raw milk			
Weighted average	23.06	23.21	22.49
Minimum	20.32	22.71	20.18
Maximum	28.79	23.99	29.36
Marginal values, €/kg solid[1]			
FAT	2.82	2.82	2.82
PRO	4.28-5.52	4.78	4.3-5.52
LAC	0.23	0.23	0.23

[1]FAT = fat, PRO = protein, LAC = lactose

Table 5. Annual financial results in the NoQuota scenarios:
Turnover, surplus, profit, producer milk price and milk solids marginal values

Annual financial results	Base prices (100%)[2]		Reduced prices (85%)[3]	
	NoQuota-Invest-BP	NoQuota-Smooth-BP	NoQuota-Invest-RP	NoQuota-Smooth-RP
Profit calculation, '000 €				
Turnover	124,339	126,496	108,884	110,693
Surplus	85,251	87,758	69,795	71,980
Milk cheque	-75,081	-79,496	-59,015	-62,414
Profit	10,169	8,262	10,780	9,565
Surplus, €c/kg raw milk	24.83	25.56	20.33	20.97
Profit, €c/kg raw milk	2.96	2.41	3.14	2.79
Marginal producer milk price, €c/kg raw milk				
Weighted average	21.87	23.16	17.19	18.18
Minimum	20.04	22.35	15.74	17.64
Maximum	28.54	23.99	22.80	18.86
Marginal values, €/kg solid[1]				
Fat	2.82	2.82	2.33-2.34	2.33
Protein	4.13-5.52	4.62-4.78	3.46-4.63	3.87-3.96
Lactose	0.23	0.23	0.14	0.14

[1]FAT = fat, PRO = protein, LAC = lactose
[2]Prices for all products identical with base prices (BP).
[3]Prices for manufactured products reduced to 85% of base prices (RP).

6.3. Product mix

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 to casein and cheese output as specified in the by-products function.

The full product portfolio was manufactured in the months of higher intake, i.e. in 5 months in NoQuota-Invest-BP/-RP, in 2 months in Seasonal and 1 month in Baseline. NoQuota-Smooth-BP/-RP produced all products except for SMP in 2 months and Smooth did not engage in the production of WMP and SMP at all. The seasonal scenarios included a higher tonnage of milk powders as opposed to the smooth milk intake scenarios, which focused on a larger proportion of the more profitable products casein and cheese. This was true for Seasonal (1,865 tons) and Baseline (1,311 tons) as compared to Smooth (0 tons), as well as for NoQuota-Invest-BP/RP (4,795 tons) as compared to NoQuota-Smooth-BP/RP (411 tons) (Table 6).

6.4. Milk solids marginal values

A relatively uniform product mix resulted in invariant marginal values for all milk solids in Smooth and NoQuota-Smooth-BP (FAT: €2.82, PRO: €4.78, LAC: €0.23) as well as NoQuota-Smooth-RP (FAT: €2.33, PRO: €3.96, LAC: €0.14), whereby the PRO value exceptionally dropped to €4.62/€3.87 in the peak month of NoQuota-Smooth-BP and NoQuota-Smooth-RP, respectively.

Likewise, FAT and LAC achieved stable values throughout the year in Baseline, Seasonal and NoQuota-Invest-BP (FAT: €2.82, LAC: €0.23) as well as NoQuota-Invest-RP (FAT: €2.33-€2.34, LAC: €0.14). However, the diversified product mix in these scenarios led to larger variations in the PRO marginal values which were lowest during the peak and highest in the shoulder periods (Baseline: €4.28-€5.52, Seasonal: €4.30-€5.52, NoQuota-Invest-BP: €4.13-€5.52/RP: €3.46-€4.63) (Tables 4 and 5).

Table 6. Product mix by scenario and month

Output (tons)	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	256	407	607	569	595	535	571	571	571	580	527	286	6,076
Cheddar			602	1,500	1,875	1,875	1,875	1,539	1,109	809			11,184
Casein	140	235	357	357	357	357	357	357	357	357	330	167	3,729
WMP			298	298	298	279	6						1,179
SMP					133								133
WheyP	227	380	860	1,280	1,455	1,455	1,455	1,298	1,097	956	535	271	11,271
Lactose	40	97	205	273	297	283	268	182	93	73	25	15	1,853
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	635	619	616	564	535	540	565	572	574	594	610	629	7,053
Cheddar	691	534	920	1,047	1,218	1,063	1,047	970	834	802	635	657	10,418
Casein	357	357	357	357	357	357	357	357	357	357	357	357	4,284
WMP													0
SMP													0
WheyP	901	828	1,008	1,068	1,148	1,075	1,068	1,032	968	954	875	885	11,811
Lactose	172	166	185	169	172	166	175	156	124	129	126	151	1,892
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	30	18	586	596	750	584	567	574	576	588	596	30	5,495
Cheddar			21	1,875	1,875	1,875	1,875	1,738	1,382	1,080	596		12,318
Casein	5	0	357	357	357	357	357	357	357	357	357	4	3,222
WMP			298	234	298	298	162						1,289
SMP					459	117							576
WheyP	8	0	588	1,455	1,455	1,455	1,455	1,391	1,225	1,083	857	7	10,980
Lactose	1	0	127	299	316	314	292	216	128	96	37	0	1,828
NoQuota-Invest-BP/RP													
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	351	538	638	743	962	878	807	637	589	601	579	388	7,712
Cheddar			1,134	1,875	1,875	1,875	1,875	1,875	1,775	1,400	274		13,958
Casein	197	314	357	357	357	357	357	357	357	357	357	232	3,955
WMP			372	372	372	372	372	372					2,232
SMP				339	915	728	480	101					2,563
WheyP	318	508	1,109	1,455	1,455	1,455	1,455	1,455	1,408	1,233	706	376	12,935
Lactose	56	130	264	310	298	284	269	204	119	93	33	21	2,081
NoQuota-Smooth-BP/RP													
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	672	646	648	583	545	552	584	592	594	619	640	664	7,340
Cheddar	1,247	746	1,534	1,694	1,875	1,713	1,694	1,598	1,428	1,389	1,180	1,205	17,303
Casein	357	357	357	357	357	357	357	357	357	357	357	357	4,284
WMP		372			39								411
SMP													0
WheyP	1,162	927	1,296	1,370	1,455	1,380	1,370	1,326	1,246	1,228	1,130	1,142	15,032
Lactose	220	186	237	217	217	212	223	200	159	165	162	194	2,393

6.5. Marginal producer milk price

The milk solids shadow prices allow the marginal producer milk price to be derived on a monthly basis, which is then linked to the monthly raw milk volume in order to identify the weighted average annual milk price. Smooth achieved a weighted average price of €c23.21 followed by €c23.06 in Baseline and €c22.49 in Seasonal (Table 4). NoQuota-Smooth-BP and NoQuota-Invest-BP registered a milk price of €c23.16 and €c21.87, whereas NoQuota-Smooth-RP and NoQuota-Invest-RP achieved €c18.18 and €c17.19, respectively (Table 5). Published data on the manufacturing milk price paid in 2009 indicates a similar weighted average of €c22.44 per kg (CSO, 2010).

The producer milk price is broken down into 4 elements, i.e. a reward for the FAT, PRO and LAC components and a volume deduction covering milk handling and fixed costs. Linking monthly raw milk composition to milk solids marginal values effectively caused (Smooth, NoQuota-Smooth) or amplified (Baseline, Seasonal, NoQuota-Invest) milk price fluctuations (Figures 1 and 2). In the smooth scenarios, the FAT element of the milk price varied marginally more than the PRO element, as opposed to the seasonal scenarios in which the PRO price element fluctuated more than the FAT element. Across all scenarios, the PRO element was approx. 50% higher in value than the FAT element (weighted avg), the LAC element was negligibly small.

Figure 2: Effects of production seasonality on the marginal producer milk price in the quota-constrained scenarios

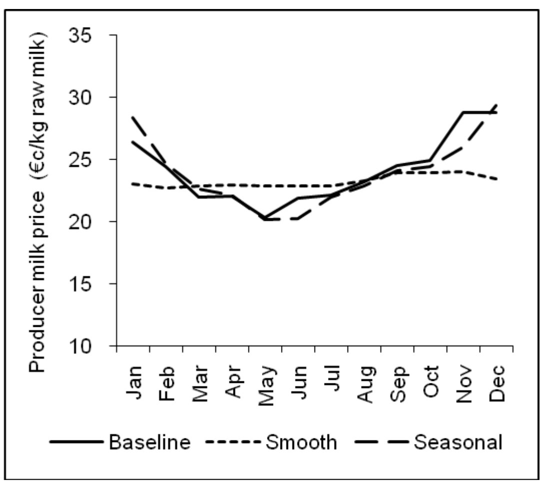
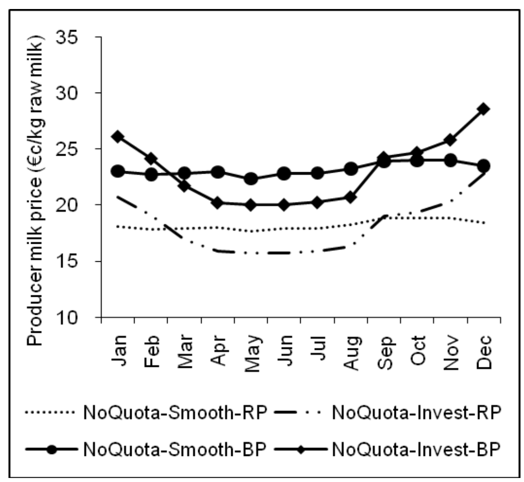


Figure 3: Effects of production seasonality on the marginal producer milk price in the NoQuota scenarios



6.6. Processor profit

Smooth (€8.1m) and Seasonal (€8.1m) achieved a higher profit than Baseline (€7.3m). Again, the variation across these scenarios is only minor. NoQuota-Invest realized a higher profit (BP: €10.2m/RP: €10.8m) as opposed to NoQuota-Smooth (BP: €8.3m/RP: €9.6m).

Profit per kg of raw milk was at a comparable level in both the quota-constrained (Smooth: €c2.94, Seasonal: €c2.95, Baseline: €c2.66) and the post-quota scenarios (NoQuota-Invest-BP: €c2.96/RP: €c3.14, NoQuota-Smooth-BP: €c2.41/RP: €c2.79) (Tables 4 and 5).

It is important to bear in mind that these profit figures do *not* express that a seasonal situation is more profitable than a non-seasonal situation; instead a lower profit is a result of a higher milk price payable (discussed below).

7. Discussion

7.1. Model results

7.1.1. Processor profit and marginal producer milk price

The marginal producer milk price was derived from the component (FAT, PRO, LAC) marginal values obtained in the model solution and this price was subsequently used to calculate processor profit. In the NoQuota-BP scenarios, profit expressed as €c/kg of raw milk was in fact lower than in the NoQuota-RP scenarios which assumed a 15% product price cut. It is apparent from these figures that, in the model, product price cuts were effectively passed on to the producer in the form of a lower producer milk price. In practice, however, the milk price identified by the model may not be sufficient for milk producers to stay in business, which needs to be acknowledged when interpreting the profit figure. Whereas the identified shadow milk price suggests how valuable 1 kg of raw milk is to the processor in the modelled situation, it cannot predict which price is going to be paid in a real-world situation. The latter will also depend on the bargaining power of the processor and the producer. This concern can be accounted for in an integrated producer-processor model or by determining a minimum milk price payable to the dairy farmer.

7.1.2. Processor profit and processor surplus

The fact that Baseline achieved a higher surplus but a smaller profit than Seasonal is also explained by the marginal milk price: The higher Baseline milk price incurred higher milk cheque costs which in turn pushed the profit below what was achieved in Seasonal. It is therefore suggested that the profit figure may be used when looking at individual scenarios, but the surplus per kg of raw milk figure should be given preference when comparing and contrasting scenarios. The surplus figure reflects the amount available for covering the cost of raw milk, processor profit and any other items applicable (e.g. extraordinary depreciation, dividends, taxes).

7.1.3. Processor surplus and fixed costs

Among the quota-constrained scenarios, Smooth emerged as the most favourable option for the processor as the surplus realized was the highest of all scenarios as well as capacity utilization and product mix were relatively stable throughout the year. Pursuing a non-seasonal pattern calls for an evenly distributed milk intake which would require altering the national calving pattern. However, alterations to national calving pattern can only be secured by processors either compelling or incentivising producers to engage in non-seasonal production. Previous research has shown that the likely seasonal price incentives would need to be substantial given higher feed costs associated with year-round calving. In addition to seasonal price incentives, dairy processor investment into processing equipment would be necessary if the product mix were to be changed from commodities output towards more profitable or value-added products.

On the other hand, a processing business aligned to a smooth milk intake curve generally requires less processing capacity and thus has lower overhead costs due to the absence of major milk production peaks. The Smooth scenario, however, observes 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 the Baseline scenario. The fixed costs imposed on Smooth were seen as “sunk costs” which means that the overheads incurred by the plant in Baseline were irreversible, and that no fixed costs savings were realized when switching to a smooth intake curve.

Baseline and Seasonal, which are closer to Irish reality, generated marginally lower surpluses (–€1.2m and –€1.9m, respectively) than Smooth while operating a seasonal intake curve and paying a higher milk price off-peak season.

NoQuota-Smooth-BP/RP registered a somewhat higher surplus (BP: +€2.5m/RP: +€2.2m) than NoQuota-Invest-BP/RP. Again, switching from a seasonal to a non-seasonal pattern while processing capacities are in place for a seasonal industry, the cost of converting to non-seasonal operation could easily exceed the gains from doing so.

However, there is scope to improve processor profitability when flattening the milk intake profile, viz. in the transition from a seasonal quota-constrained situation to a smooth intake curve in a liberalized market with a larger milk pool. No investment was required in NoQuota-Smooth-BP/RP to manage the additional milk supply and the capacities carried over from Baseline were better utilized throughout the year.

7.1.4. Production seasonality and product mix

The non-seasonal scenarios focused on manufacturing the more profitable products and consequently differed from the seasonal scenarios with respect to the product portfolio. NoQuota-Smooth-BP/RP, for instance, showed a far higher cheese output (+24%) than NoQuota-Invest-BP/RP and very little milk powder output. In a real-world situation, this would have implications when switching to a different milk intake pattern insofar as 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 liberalized 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.

7.1.5. Implications for Ireland's milk processing sector

With respect to the Irish dairy processing industry in a quota-constrained situation, model results suggest that under the current quota-regime maintaining seasonal production is preferable over a smooth production pattern as (a) the capacities required for production peaks are in place, (b) the cost of switching to year-round production is substantial while at the same time (c) the modest gains from pursuing year-round production could quickly be exhausted by the financial burden of switching to an even pattern. Likewise, the gains of switching from a seasonal to a smooth production pattern post milk quota do not appear sizeable enough once the processing capacities are constructed to cope with an increased peak milk supply. A key question would be who (i.e. the milk producer or processor) will bear the cost of expansion (e.g. plant investment, fleet extension).

Since (a) the Irish dairy processing sector is adapted to a seasonal dairy production at present and (b) Irish milk producers are expected to significantly upscale supply post milk quota abolition in 2015, the findings suggest that Ireland's milk processors could benefit from converting to a smoother milk supply pattern once the milk quota system is dismantled. Regarding the expected output growth post milk quota abolition, the Irish Dairy Board presently investigates Ireland's future product mix options and potential markets, such as emerging economies (IDB, 2010).

Other than that, and compared to a non-seasonal mode, 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).

Considerations on the transferability of these results to practice are elaborated below.

7.2. Data caveats

The model structure allows for the specification of prices, variable and fixed costs, raw milk and product types, milk pool and product composition as well as input and output maxima on a monthly basis, thereby facilitating the analysis of seasonality-incurred irregularities. Given fixed monthly processing capacities, the analysis focused on the implications of seasonality on the processors product mix. Specifically, seasonality imposes costs on the processor as it reduces the proportion of milk that can be used for more profitable products such as cheese.

However, one weakness was the lack of data that would have permitted more detailed analysis of the operational costs of seasonality for the processor, such as milk collection, labour and storage costs.

7.2.1. Milk collection

In shoulder periods, for instance, serving the standard milk collection route on a daily basis is not likely to fill the tanker which would be uneconomical in the sense that the total cost per collection (e.g. labour, diesel) would be spread over a considerably lower milk volume. In practice, longer distances are travelled or the number of collections is reduced in order to fully utilize a tanker's capacity. Transport charges vary according to the milk producer's scale and the frequency of collection (IFJ, 2010). Even though research currently conducted by Quinlan (UCC, Cork, Ireland, personal communication) suggests that the difference in transport costs per unit of raw milk in seasonal and smooth systems is relatively minor, the practical seasonality-incurred implications, such as longer fleet and labour working hours in the peak period, need to be recognized when analyzing seasonal systems.

7.2.2. Labour productivity

In seasonal dairy markets, labour productivity varies in the course of the year: On the one hand, hiring cheaper seasonal labour during months of peak milk intake decreases direct labour cost per unit of output. On the other, direct labour cost per unit of output may vary where permanent workforce handles a higher throughput during peak months and a lower throughput in shoulder periods provided hourly wages remain constant.

7.2.3. Storage

Monthly storage costs per unit of output, entailed by items such as rent or energy consumed by refrigeration, are lower when storage space is fully utilized, or higher in times of poor utilization. Assuming a relatively stable demand throughout the year, storage costs per unit of output are likely to be higher for products manufactured in peak months when supply exceeds demand and excess production is put on stock. Apart from storage seasonality occurring during the year, perennial developments were not considered since the proposed model covers only a 1 year time horizon. In practice, output seasonality arising from demand at international markets or from agricultural policy may spread over several years and necessitate elongated periods of storage. Hennessy and Roosen (2003) argued that measures implemented in the EU's CAP assisting price stability (i.e. private storage subsidies and public intervention buying), are intrinsically counter-productive; they tend to encourage the manufacture of the targeted commodities since intervention purchases can be seen as secure income, which ultimately results in aggravated seasonality.

7.2.4. Cross-price elasticities

Given a considerably larger milk pool post-quota, a decrease in prices is likely for products which are manufactured from the extra raw milk.

The increased milk volume in the NoQuota-scenarios had an impact on both product yield and product mix. In absence of suitable cross-price elasticities, all product prices were cut uniformly by 15%. However, in a real-world situation – depending on which products would be manufactured from the additional milk volume – the prices of those products are expected to decrease unequally and to also affect other dairy products' prices. The extent of this decline post-quota and how to best manage price shocks are crucial questions for a seasonal Irish dairy industry.

Amongst others, the limitations discussed above need to be acknowledged when interpreting the model results.

7.3. Industry level interdependencies and considerations

The processor model is set up to provide guidance on how variations in the milk supply pattern affect a dairy processor's financial performance, product mix and marginal producer milk price. By merging the processor model with a farm-level model it would be possible to estimate optimal levels of seasonality at industry level. Specifically it could address the question of whether Irish dairy farmers would benefit from a smoother milk supply pattern coupled with the industry's shift to the manufacture of value-added products motivated by less volatility and higher prices achievable, while some considerations would have to be taken on the potential to market these products. With respect to the relatively small processor gains from smoothing supply reported in this paper, it may be the case that these benefits would quickly be outweighed by increased farm-level costs associated with a move to non-seasonal milk production.

8. Conclusions

It has been demonstrated in this paper that the multi-period optimization model as discussed above proves useful in analyzing the financial effects of seasonal milk production at processor level. However, the availability of more detailed processing data especially in relation to operational costs of seasonality, such as transport, product storage and labour utilization, would undoubtedly enhance the informative value of the model. It is proposed that a natural extension to the work reported in this paper at national level would be an integrated producer-processor model providing a more holistic industry-level perspective. Potential future research could target a refined analysis of seasonality-incurred impacts on activities, such as the storage or labour component, or the joint analysis of financial (e.g. surplus), environmental (e.g. greenhouse gas emissions) and social sustainability (e.g. employment levels, income distribution) indicators.

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