Identifying Robust Milk Production Systems

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Abstract

The European dairy industry faces an increasingly uncertain world. There is uncertainty about subsidy payment levels and compliance conditions, global competition, price variability, consumer demand, carbon footprints, water quality, biodiversity, landscapes, animal welfare, food safety, etc. The future is uncertain because it cannot be reliably predicted; therefore the industry must adopt production systems that will be financially robust over a wide range of possible circumstances. Adding to the uncertainty is a lack of consensus regarding the specific characteristics of these sustainable production systems. In this interdisciplinary research project we developed a profit maximizing whole-farm model and employ it to identify robust milk production systems for Northern Ireland under varying market, policy and farm family conditions. The milk production systems incorporated into the model involve variations in date of calving, quantity of concentrate fed, and nature of forage utilized. The model also incorporates a disaggregated specification of time use within farm households and links intra-household resource allocation to the process of agricultural technology adoption. This work illustrates how profit maximizing whole-farm models can play a decision support role in helping farmers, agricultural researchers, agribusiness advisers and agricultural policy makers to identify economically sustainable agricultural production systems.

Introduction

The European dairy industry is facing an increasingly uncertain world. There is uncertainty about subsidy payment levels and associated compliance conditions, global competition, price variability, consumer demand, carbon footprints, water quality, biodiversity, landscapes, animal welfare, food safety, etc. The future is uncertain because it cannot be reliably predicted; therefore the industry must adopt business strategies that will be financially robust over a wide range of possible circumstances. Adding to the uncertainty, however, is lack of consensus regarding the specific characteristics of these robust milk production systems. Some suggest that the intense pressure of an open market environment will require the adoption of low cost production methods such as those adopted in New Zealand. Others point to the USA where farmers survive by keeping very high yielding cows and relying more on conserved forage. In this interdisciplinary research project we developed a profit maximizing (linear programming) whole-farm model and employ it to identify robust milk production systems for Northern Ireland under varying market, policy and farm family conditions.

Farm Household Behaviour- background and rationale

The primary focus of agricultural policy within the European Union has been to support farm incomes. Successive Common Agricultural Policy (CAP) reforms have prioritised the promotion and preservation of family farms as a core objective, in response to concerns such as maintaining the fabric of rural society and protecting of the countryside (Commission, 2002). From a European policy perspective the main support mechanisms have focused on the performance and profitability of the farm business.

However as in other dimensions of policy, there has been an increased interest in exploring economic performance from the perspective of the household. For example, the recently established Commission on the Measurement of Economic Performance and Social Progress (CMEPSP) has made a number of recommendations in relation to the development of relevant indicators of social progress and overall well being. The Commission also acknowledges that ‘well being’ does not rely wholly on income and other material living standards, but also depends on other dimensions such as health, education, personal activities (including work), political voice and governance, social connections and relationships, the environment, etc (Stiglitz et al., 2009).

Over recent years many farm households have faced the increasing challenge of balancing farm and non-farm work activities as they have sought to maintain household income. In so doing, farm families make choices and decisions about their level of commitment to the farm business, diversification activities and off farm employment. As well as undertaking paid employment, farm operators and their partners do a lot of things for themselves, their families and their communities for which they don’t get paid, such as caring for others (children and elderly or infirm relatives), housework and voluntary activities. The increased demands on households’ time can have implications for business decisions in relation to how the farm is managed and developed and can also affect farm family lifestyles and well being.

Models of Household decision Making Behaviour

Since Becker’s seminal work in 1965 the microeconomic literature has demonstrated a growing interest in household decision-making models. From the welfare maximizing perspective Samuelson, 1956 applied a unitary model of household decision making assuming that individuals within the household acted as if they were maximizing a social welfare function. In Becker’s model (1965), he assumed that if a dominant individual is managing the household’s resources, they will maximize utility subject to the household income constraint; i.e. there will be income pooling. Becker’s unitary model, for purposes of analysis, identifies that individuals’ and groups’ utility functions have to be separated. In an extension of Becker’s model, Gronau (1977) incorporated and developed the unitary model to include labour allocation to the market, home production1, and leisure. Gronau’s model identified that time is used at home to produce home goods that are

[1] *Home production includes cooking, cleaning, laundry, gardening, household shopping, routine household maintenance*

perfect substitutes for market goods, where home production is subject to diminishing marginal productivity. An increase in the market wage rate is expected to reduce work at home, while its effect on leisure and work in the market is indeterminate. An increase in income increases leisure, reduces work in the market, and leaves work at home unchanged.

More recently, Chiappori's work on non-unitary household models has ignited renewed interest in household decision-making most particularly from the perspective of how decisions are made within the household. In unitary models, allocation of household members to tasks reflects their comparative advantage, not differences in bargaining position. Pareto optimality is the defining property of the "collective model" approach of Chiappori (1988, 1992), the models do not assume that the choices of the household can be represented as resulting from the maximization of a utility function. Non-unitary models including cooperative models, characterize the equilibrium distribution by means of a set of axioms, one of which is Pareto optimality.

Rather than applying a particular cooperative or non-cooperative bargaining model to the household allocation process, Chiappori's models demonstrate that, given a set of assumptions including weak separability of public goods (for example, children in the household) and the private consumption of each family member, Pareto optimality implies, and is implied by, the existence of a "sharing rule." The preference factors are the same as those in the unitary model, whereas the distributional factors are factors influencing the decision process through a ''sharing rule'' (Browning & Chiappori, 1998). Under a sharing rule, the family acts as though decisions were made in two stages, with total family income first divided between public goods and the private expenditures of each individual. These preferences may be selfish (were the individual cares only about their own consumption), altruistic (were they care about the utility of other members of the household), or paternalistic (care about the consumption of other members of the household).

The opening up of the 'black-box' of household decision-making and investigating the household from the perspective of individuals directing household choices in line with their own individual preferences has stimulated a wide body of research from a number of different household decision-making aspects; for example, income pooling, consumption decisions and labour allocation; (See Lundberg et al. 1997; Apps and Rees 1996; 2002; Browning, Bourguignon, Chiappori, & Lechene, 1994; Chiappori, 1988, 1992; Manser & Brown, 1980; McElroy & Horney, 1981; Phipps et al. 1998). Researchers have also debated the determinants of bargaining power, for example, whether the threat of divorce is the correct assumption or whether the threat of non-cooperation within marriage is a more reasonable assumption (See Lundberg and Pollak 1993).

Decision making and farm households

From a farm household perspective, traditionally farm-level micro-analysis has focused on the farm business as the main unit of analysis. However given the increased interest in modelling household-decision making in the wider economic literature there has been an increased interest in the decision-making process within family farm households and how the main household decision makers, namely the operator and spouse(if applicable) influence the economic well-being of the household and how those decisions ultimately impact on farm performance. Within the context of farm households, the decision process regarding how resources are allocated has an important bearing upon choices in terms of family consumption versus farm investment; time devoted to on and off-farm employment activities as well as leisure; gender–based division of labour within the household; human capital formation and education decisions; and finally, farm production response to market and policy based incentives.

Although farm households are a diverse group decisions about resource allocation, particularly labour and time-use, will be based on farm, individual and household characteristics. For example, the size of a farm, the enterprise types or the decision to manage a farm in a more extensive way may result in a lower labour requirement and therefore allowing more labour to be supplied to off-farm employment. Furthermore, a higher level of human capital and/or the proximity of some farms to larger towns and cities may allow for more off-farm employment opportunities for the members of the household. The decisions household members make regarding how they divide their time, labour (i.e. the decision to secure off farm employment) and financial resources drive the household's income level and the economic well-being within the household. In managing farm resources farm operators make important land, enterprise, stock and financial decisions. Therefore farm business decisions, regarding technology adoption and production decisions are increasingly influenced by labour availability within the farm household, (Fernandez-Cornejo et al. 2007).

Time devoted to on and off-farm employment activities for example on-farm and off-farm activities compete for limited managerial time (mainly of the operator and spouse). How farm operator households allocate their time largely affects production decisions (such as technology adoption), economic performance, and the household's economic well-being. The decision by farm households to allocate labour to farm and off-farm activities reflects the returns for the alternative use of that labour. The income that the farm operator or spouses can obtain working off-farm is often used to measure the opportunity cost of the operator or spouses farm labour (Fernandez-Cornejo 2007). Increased participation by farm based females in the wider labour market may raise concerns as to how households have adapted. Changing household patterns of employment due to women's increased labour market participation may cause a redistribution effect within the farm household in terms of home production, caring responsibilities, leisure and time spent in farm work.

This also extends to wider unpaid family labour. Many farm households, particularly dairy farm households, rely on the labour provided by adult children within the household, particularly at critical times throughout the year. If this labour goes off-farm then this may increases the labour demands on the farm operator and spouse (Zepeda and Jongsoog, 2006). Increasing household income may add to farm household resources but it also vies for farm-managerial time, caring time and leisure time. Smith (2002) showed that as the farm operator and other household members engage in off-farm activities less time is available for farm management. A particular research question which arises is how off-farm employment impacts on the economic performance of farm businesses; for example off-farm income may improve household efficiency but may also impact on farm efficiency.

In terms of farm operators, off-farm work is less likely for those enterprises which are more labour intensive (dairying). Dairy enterprises require long working hours and the opportunity cost of a dairy farmer to go off-farm to work is higher than for those in other enterprises such as beef and sheep (reference). Increasingly studies are exploring technology adoption within farm businesses and the factors that influence these decisions. In some cases, labour-using technology has been replaced by capital intensive, labour-saving technology. As farms adopt new technologies of different kinds and at different rates, this may impact on the cost structure but also the resource allocation decisions for these farms (Chavas 2001; Lu 1985).

Furthermore, current household production decisions by farm operators and their spouses affect future production or consumption possibilities. For example, the accumulation of human capital will increase productivity in the home or wages in the market so the ability of family members to make medium to long term investment commitments is crucial. In turn this will have implications for how farm families allocate time to farm and off-farm work, other household production activities, leisure and human capital formation.

Previous research has identified that increased demands on households' time can have implications for the farm family lifestyles and well being. Jongsoog and Zepeda (2004) used a Nash-cooperative bargaining framework to examine how members of US family farm households allocate their time between work and leisure. Time allocation categories for parents include farm, off-farm, and household work, as well as leisure time; for children, the categories are farm work and leisure time. Most notably, the results confirm that US women and children make significant labour contributions and that both women and men are decision-makers regarding their own and their children's time allocation. The results also show that intra-household time allocation on US farms is gender specific, and that the father's economic status has the largest impact on the time allocation of household members. The findings also confirm that children's labour makes an important economic contribution to the operation of their family farm.

This paper seeks to incorporate the dimension of 'time –use' into a profit maximizing farm household model in order to examine the robustness of a range of dairying enterprise systems; robustness not only from the perspective of farm profitability but also from the perspective of optimising household labour allocation decisions. Rather than examining the farm business or farm household in isolation, this integrated approach captures the interplay of farm and nonfarm decisions in terms of farm and non-farm work and other time commitments such as caring and home production.

Background to household time-use data

In order to account for how farm household choose to allocate their time and incorporate this into the model, we used data from a farm household survey which was conducted in March 2008. The survey aimed to explore the decisions made by farm operators and their spouses regarding how they use their time. The target sample group was farm operators who were partnered and were likely to have dependent children. The over 65 age group were less likely to have dependent children and were therefore, excluded from the sample selection. The age limits for farm operators were set at between 25 and 65 years. The sample frame focused on the main pastoral based enterprises namely; dairying, cattle and sheep. In order to insure anonymity of all respondents and given the relatively small number of arable and intensive production enterprises in Northern Ireland, these farm households were not included in the final sample selection.

Therefore, the sample selection criteria were as follows:

- Farm operator - married/partnered, aged between 25 and 65 years
- Farm types- Dairy, Beef/Sheep (LFA), Beef/Sheep (Lowland)
- Farm size (SLR) -Greater than or equal to 0.25 SLR

A stratified random sample of 900 farm businesses by farm-type and farm size, provided adequate representation of both ‘full-time’ and ‘part-time’ farm operators. This sample was also selected to be representative spatially across Northern Ireland. The final sample database consisted of 688 farm businesses and 1376 individuals. Of the final sample, 233 were dairy farms (See table 1).

Table 1 Farm Household Survey Sample by Farm Type

Farm Business Type	n	%
Dairy (LFA & Lowland)	233	33.9
Cattle & Sheep (SDA, DA & Lowland)	455	66.1
Total	**688**	**100**

The Northern Ireland Agricultural Census 2008 (Department of Agriculture and Rural Development [DARD], 2009) indicates that the there were just over 3,400 dairy farms operating in Northern Ireland. The Farm Household Survey with 233 dairy farms represents 6.7% of the entire dairy farm population in Northern Ireland. An examination of key farm household and business characteristics indicates that within certain parameters, the sample of 233 farm households is largely representative of the wider dairy farming population when compared with the EU Farm Structure Survey (DARD, 2008) and Agricultural Census data (DARD, 2009).

In terms of age distribution of the farm operator, as the survey was aimed at targeting those operators between the age of 25 and 65 the farm household survey sample has a slight higher representation of younger farm operators and an under representation of those aged 55 years and older. However it is representative of the biggest cohort of dairy farm operators in Northern Ireland, those aged between the ages of 35 and 54 years (See Table 2).

Table 2 Comparison of the Age Distribution of Dairy Farm Operators from the Farm Household Survey sample and the Projected Population

Age Groups	Projected Population 2007[2] Dairy Farm Operators		Farm Household Survey Data 2008 Dairy Farm Operators	
	n	%	n	%
under 24 years	11	0.5	6	2.6
25 - 34 years	77	3.8	51	21.9
35 – 44 years	464	23.2	82	35.2
45 - 54 years	720	35.9	85	36.5
55 - 64 years	732	36.5	9	3.9
Total	2,004	100	233	100

In terms of farm business characteristics Table 3 presents the average figures for the most recent available years for farm size and dairy herd size from existing databases (EU farm Structure survey and Agricultural Census[3]).

Table 3 Comparison of the Farm and Herd size of Dairy Farms from the Farm Household Survey sample, the Agricultural Census of Northern Ireland and the EU Farm Structure Survey

	EU Farm Structure Survey 2007	Agricultural Census of Northern Ireland 2008	Farm Household Survey Data 2008
Average farm size (acres)	168	-	144
Average size of Dairy herd	79	73[4]	66

[2] The projected population data reflects 2007 EU Farm Structure Survey data averages raised to provide estimates of the population. Unmarried farm operators and those over the age of 65 years were excluded to facilitate a fair comparison with the Farm Household Survey data.

[3] It should be noted that the EU Farm Structure Survey data represents survey data averages relating to dairy farms raised to provide estimates of populations, whereas the Agricultural Census is an official collection of data from all farm businesses operating in Northern Ireland at the time of the Census.

[4] This average herd size was calculated using data from across all farms recorded as having dairy cows (n=3,975). The Census recorded 3,457 dairy farms at the time of data collection and therefore it is reasonable to assume that the average herd size for dairy farms would be greater than the average of 69.

The dairy farms within the Farm Household Survey sample are slightly smaller on the basis of farm area and dairy herd size, compared to the EU Farm Structure Survey average. This may reflect the incorporation of the spatial criteria within the household sample to obtain a full-geographical spread of farms across Northern Ireland. However the average herd size of the Farm Household Survey sample dairy farms is more in line with the average herd size from the Census results[4].

Selection of Dairy Farm Household Typologies

For all households, the presence of children has an effect on market versus domestic time allocation decisions (Apps and Rees, 2005). In line with Apps and Rees approach we identify 'life cycle' phases for the presence and ages of children within a household, in order to capture the key transitions in the life cycle of the typical household and to demonstrate the demands that caring fro children place on allocation of time, for both the farm operator and spouse. Previous work by Apps and Rees has shown that the arrival of children within a household results in female labour supply falling, while domestic hours of work more than triple and as a result household income falls. Furthermore as children reach school age and beyond female market hours gradually increases and domestic hours fall. In terms of household males, their findings suggest that male market hours and full time employment change very little until they begin to approach retirement.

Drawing on this 'life cycle' definition we identify four household typologies based on the presence and age of children within the dairy farm household. The typologies are as follows:

Household Group A: '*Younger Households*'. This particular household typology indicates the presence of children under the age of 10 years within a household. These 'younger' households may also have children whom are older than 10 years of age.

Household Group B: '*Older Households'*. This group of dairy farm households includes those households with children between the ages of 10 and 15 years. These 'older' householders do not have any children under 10 years of age but may have children aged 16 years and over.

Household Group C: '*Households with no children under 16 years'*. These households do not have any children under the age of 16 years living in the household but have more than two family members living in the household. It should be noted that this group may include those households with children aged 16 years and older living in the household, and should only be interpreted as an indicator of households where there are no young[5] dependent children resident.

Household Group D: '*Farm Operator-Spouse only Households'*. These households consist only of the Farm Operator and his/her Spouse. These couples may have older children who are not living in the household or they may never have had children.

In examining time use for these four household typologies we can observe and control for life cycle effects.

[5] Children aged under 16 years.

Using these household typologies, we analysed dairy farm operators and their spouses' allocation of time across four main activities: on farm labour, off farm labour (employment and self employment), caring and home production activities. The summary statistics are presented in Table 4 :

Table 4 Time Use of Farm Operators and their Spouses

	Household Group A: ***'Younger Households'***	**Household Group B:** ***'Older Households'***	**Household Group C:** ***'Households with no children under 16 years'***	**Household Group D:** ***'Farm Operator-Spouse only Households'***	**All Households**
Farm Operators					
Average Age	42	50	57	57	51
Annual Hours					
On Farm Labour (annual hrs)	3,998	3,376	3,479	3,591	3,618
Off Farm Labour	119	271	205	166	186
Caring	790	671	123	100	403
Home Production	81	159	72	139	104
Total	**4,988**	**4,477**	**3,879**	**3,996**	**4,311**
Spouse					
Average Age	38	47	55	55	49
Annual Hours					
On Farm Labour	356	386	520	364	419
Off Farm Labour	604	622	390	568	527
Caring	3,210	1,633	255	157	1,308
Home Production	1,616	1,583	1,695	1,553	1,630
Total	**5,786**	**4,224**	**2,860**	**2,642**	**3,884**

The Model

Production Systems

The model methodology is an extension of a previous study (see Anderson *et al.* 2009). It contains eleven dairy system options. There are six standard grass silage systems (i.e. where grass silage is the only winter forage used), namely, three spring-calving systems with average milk production per cow of 5,000 (S5), 6,000 (S6) and 7,000 (S7) litres, and three autumn-calving systems with 6,000 (A6), 7,000 (A7) and 8,000 (A8) litre yields. There are also three autumn calving systems that use grass and maize silage winter diets with 6,000 (AM6), 7,000 (AM7), and 8,000 (AM8) litre yields, and two non-seasonal calving 10,000 litre confinement systems (NS10 uses only grass silage while NSM10 uses both grass and maize silage). Typical Northern Ireland conditions are assumed for grass and maize silage quality, grazing management, and genetic merit of cows. Standard lactation curves for Northern Ireland dairy cows are used (Lennox, 1992) with average daily milk yields calculated for each month. College of Agriculture, Food and Rural Enterprise (CAFRE) Benchmarking data (Hopps, 2001), along with other sources (e.g. Keady *et al*., 1997), were used to estimate the average butterfat and protein percentage of the milk produced from each system. Cows in the autumn-calving systems are assumed to calve on 15 November, have a 305-day lactation, go to grass on 15 April, are dried off on 15 September and are housed on 15 October. Cows in the spring-calving systems are assumed to calve on 15 March, have a 305 day lactation, go to grass on 15 April, are housed on 15 October and are dried off in mid January. It is assumed that cows in the non-seasonal 10,000 litre confinement systems are housed for most of the time with only limited use of grazing. Grazed grass is only utilized by those cows whose late lactation and dry period coincides with the 15 April to 15 October grazing season. In the seasonal calving systems, conception is assumed to take place 85 days into lactation, with a gestation length of 280 days and calving interval of 365 days. Calving interval is a less critical factor in the high yielding non-seasonal calving systems and extends to around 400 days.

Feed Inputs

Feed inputs required to support the target daily milk yields for each system during the winter housed period are calculated using the Feed into Milk (FiM) model (Offer *et al*. 2002). For each of the model systems, live-weight loss in the first 100 days of lactation is assumed to be 0.5kg per day, with this live-weight being regained in the last 100 days of lactation. In the dry period, intakes are assumed to be 10kg DM/cow/day of either grass or silage. The cows are assumed to average 600kg live-weight. Typical summer grazing management is assumed which is taken to be a paddock grazing system with some supplementation as necessary with a grazing concentrate. Mayne *et al*. (1991) outlined the milk yield that is achievable from grazed grass in an experimental situation. However, the model assumes that in a typical farm grazing situation that milk yields achieved from grass alone would be lower than that achieved under research conditions, i.e. 30% and 35% lower in spring and autumn calving herds respectively. Grazed grass utilisation was assumed to be 75% under typical conditions. Comparisons with Northern Ireland Dairy Benchmarking data (Hopps, 2006) illustrate that the model systems are located close to the boundary of on-farm commercial reality. That is, the model is being asked to choose from a range of systems that are assumed to be operating close to the upper limits of efficiency shown to be possible in a commercial environment.

Labour Requirements

The European Dairy Farmer database (EDF, 2001) was used to calculate labour requirements per cow for the dairy systems. A multiple regression equation was estimated, where the dependent variable was milk output per hour of labour input, and the explanatory variables were average milk yield per cow and herd size (cow numbers). Labour requirements for the alternative enterprises, however, were taken from Nix

(2001). To introduce the various ‘time-use’ household scenarios the figures in Table 4 for farm labour, off-farm labour, home production and caring are allocated for operator and spouse.

Available Resources on a 70 cow Dairy Farm

This information was taken from the Farm Business Survey (1999-2000) and relates specifically to dairy herds of between 65 and 75 cows (average herd-size 70 cows). The average land area owned by farmers with 70 cow dairy herds is 44.2 hectares. Total labour supplied by the farmer, spouse and family on a typical 70 cow dairy farm is 4,513 hours. A total of £45,692 of own capital is assumed to be available to finance livestock, working capital, and machinery, with any additional capital requirements for these items needing to be borrowed. Average milk quota owned for this sample of farms is 401,967 litres. It is assumed that additional land can be rented, additional capital borrowed, additional milk quota leased, and additional labour hired.

Alternative Enterprises

Four alternative enterprises are included, namely, dairy heifer rearing, 24 month beef, lowland breeding ewes and spring barley. The dairy heifer rearing enterprise although grouped with the alternative enterprises may not be considered as a true alternative enterprise, as there is no option for selling the reared heifers or buying in replacement heifers. They enter the dairy herd at rearing cost with replacement rate fixed at a constant 25% for all the systems except the two 10,000 litre confinement systems where a 30% replacement rate is assumed. Silage and concentrate requirements are derived from the Farm Business Data-book. Grazing intakes are derived from the recommended grazing areas. It is assumed that dairy heifer, 24-month beef and lowland ewe enterprises utilise grazed grass with an efficiency of 60% (in agreement with Peel and Matkin 1984).

Overhead Costs

Overhead costs are composed of machinery running costs, depreciation on machinery and buildings, land maintenance, building repairs and other miscellaneous overheads. CAFRE BenchMarking data were used to estimate the overhead cost differences between spring and autumn systems, with spring-calving herds on average having lower machinery depreciation, land and building costs. Moreover, a simple regression model was used to analyze Farm Business Survey data in order to identify what element of overhead costs varied with cow numbers and what proportion of overheads appeared to be truly fixed. It was found that, over the relevant range, only £2,665 of overhead costs appeared not to vary with herd size, while the remaining overhead costs could be assumed to vary as a constant amount per cow (i.e. £/cow). The fixed overhead cost element (i.e. £2,665) was deducted after model solution to calculate farm profit. Overhead costs for the four alternative enterprises were derived from Farm Business Survey data. The capital requirement for all the livestock enterprises is composed of three elements, the purchase/replacement price of the animal, the machinery cost and the working capital per one production cycle. Both the working capital and the purchase/replacement price are taken from Farm Business Data-book. The machinery capital requirement attributed to each enterprise is derived from total machinery costs on 70 cow dairy farms divided between the various enterprises in terms of financial output.

Milk Purchasing Contracts

The basic milk contract incorporated into the model has four main parameters: (1) average annual base price, (2) seasonal base price variation, (3) butterfat bonus / penalty, and (4) protein bonus / penalty. It is assumed that other elements of the milk purchasing contract, such as hygienic quality, presence of added water or transport charges, are all system neutral. The average annual base price sets the basic level of milk prices received by milk producers in any given year. The seasonal variation of milk prices assumed in the model was based on the variation in base prices paid by United Dairy Farmers, the market leader in Northern Ireland's milk market, over the eight years (1995 – 2002). Finally, based on results from Lennox (1992), the model calculates (using a matrix generator) the monthly milk supply in each system, the monthly butterfat percentage of milk in each system, and the monthly protein percentage of milk in each system.

Model Solution

The profit maximizing (linear programming) model outline above was solved using the GAMS/CONOPT mathematical programming software package (Brooke et al., 1998). GAMS (General Algebraic Modelling System) is a matrix generator that was originally developed to assist economists at the World Bank in the quantitative analysis of economic policy questions. It allows modellers to generate many of the model parameters automatically, which enables model simulations to be conducted quickly and accurately. Optimisation models created with GAMS must be solved with a programming algorithm, and CONOPT is used in this case.

Results

The Optimal System as Milk Prices Change

Table 5 summarizes the results of model simulations involving changes in milk price. These are annual base price changes, with monthly milk prices varying throughout the year according to the seasonal structure of monthly base prices being assumed. The model results reported in Table 5 show the optimal milk production system when the average annual base price increases from 16ppl to 24ppl in 2ppl increments. In these model simulations it is assumed that the butterfat bonus/penalty equals 0.018p per 0.01% deviation from a standard base quality of 4.00% butterfat; that the protein bonus/penalty equals 0.032p per 0.01% deviation from a standard base quality of 3.18% protein; and that the seasonal adjustment in base prices follows the historic average.

Table 5 Annual Milk Price Simulation

	Annual Milk Price (pence/litre)				
Optimal Dairy System	**16**	**18**	**20**	**22**	**24**
Dairy Cows (hd)	35 S7[1]	60 S7[1]	70 S7[1]	75 AM8[2]	75 AM8[2]
Dairy Heifer (hd)	18	30	36	38	38
Spring Barley (ha)	23	8	2	5	5
Hire Farm Labour (hrs)	-	-	-	563	563
Farmer – farm (hrs)	2577	3810	4310	4311	4311
Farmer – home production (hrs)	1734	501	1	-	-
Farmer – caring (hrs)	-	-	-	-	-
Spouse – farm (hrs)	-	-	-	-	-
Spouse – home production (hrs)	-	1233	1733	1734	1734
Spouse – caring (hrs)	1711	1711	1711	1711	1711
Spouse – employment off-farm (hrs)	2173	940	440	439	439
Income (£) (Farm and Off-farm)	**33,761**	**40,894**	**50,301**	**60,580**	**72,192**

1. **S7** = spring-calving system with grass silage and 7,000 lt. yields.
2. **AM8** = autumn calving system with grass and maize silage and 8,000 lt. yields.

In Table 5 we see that with annual average milk prices of 16, 18, 20, 22 and 24 ppl, the optimal milk production system is either a spring calving herd, yielding an average 7,000 litres per cow (i.e. S7), or an autumn calving herd feeding grass and maize silage, yielding an average 8,000 litres per cow (i.e. AM8). At a baseline price of 20 ppl the farm keeps 70 dairy cows, 36 dairy heifers (18 under one year old and 18 from one to two years old) and grows a small amount (i.e. 2 Ha approx.) of spring barley. Annual milk production is 490,000 litres with annual income of £50,301.

The baseline for labour allocation represents the farm operator working full-time on farm (4310 annual hours). These are typically long working days with also weekend work. The farm operators supplies no time to caring or home production activities. The spouse undertakes a small amount of off-farm work (440 hours annually) and the majority of her remaining time is divided between home production (1733 annual hours) and caring (1711 annual hours). When milk prices fall to 16 pence per litre the model results indicate a shift in labour allocates between farm and non-farm activities. In response to a lower pence per litre milk price the spouse allocates significant employment hours off-farm (more than full-time, 2170 hrs annually). In order to do so, the farm operator responds by shifting employment hours from farming into home production activities. This results in the number of dairy cows reducing to 35 and income falls to £33,761. In contrast, when milk prices per litre rise to 22p and above, the spouse undertakes less work off-farm and increases home production. The farm operator moves out of home production, reallocates time to farm work and also hires in some labour, (563 hours annually) and annual farm and off-farm income is £50,301.

Relative Profitability of the Alternative Systems

Table 6 illustrates the relative profitability of the eleven systems at a milk price of 16p/litre and 24p/litre. The values in brackets represent the increase in profit per cow (£/cow) required for that system to be equal in profitability with the optimum system. A number of points are worthy of note. First, there appears to be relatively little difference in profitability between equivalent moderate input-output spring and autumn calving systems. For example, while the Spring calving 7,000 litre system is optimal at 16 ppl, it is the equivalent Autumn calving 8,000 litre systems (autumn calving systems being higher yielding) which are next nearest to the optimal system. Similarly, while the Autumn calving 8,000 litre systems are optimal at 24 ppl, it is the equivalent Spring calving 7,000 litre system which is next nearest to the optimal system. Second, it is clear that the low input-output systems are a lot closer to the optimal when milk prices are low. Finally, it is also clear that the high input-output systems are a lot more profitable than the low input-output systems when milk prices are high.

Table 6 Relative Profitability of the Systems

Rank Order at Milk Price of 16p/litre (increase in profit required for system to equal the optimum system)	**Rank Order at Milk Price of 24p/litre** (increase in profit required for system to equal the optimum system)
1. S7 (most profitable)	**1.** AM8 (most profitable)
2. AM8 (-£49/cow)	**2.** A8 (-£1/cow)
3. A8 (-£51/cow)	**3.** S7 (-£29/cow)
4. S6 (-£56/cow)	**4.** NSM10 (-£56/cow)
5. AM7 (-£110/cow)	**5.** NS10 (-£59/cow)
6. S5 (-£111/cow)	**6.** AM7 (-£133/cow)
7. A7 (-£111/cow)	**7.** A7 (-£134/cow)
8. AM6 (-£156/cow)	**8.** S6 (-£156/cow)
9. A6 (-£157/cow)	**9.** AM6 (-£251/cow)
10. NSM10 (-£241/cow)	**10.** A6 (-£252/cow)
11. NS10 (-£245/cow)	**11.** S5 (-£282/cow)

The results incorporating operator and spouse hours to paid and unpaid production by the ‘life cycle’ phases defined by the presence and ages of children within a household are presented in Table 7. The results compare the overall average for farm households against those household with younger children (columns 1 and 2 respectively). Comparing those household with young family members against the average the results clearly show the commitment to caring which occurs, most of which is undertaken by the spouse. In addition the farm operator takes on approximately an additional 13 hours of home production a week compared to the average. Table 7, Column 3, presents the results for the scenario were the female off-farm wage increases from £9 per hour to £15 per hour. Increasing the off-farm wage for the spouse results in the spouse increasing the number of hours employed off-farm and compared to the average household farm and household income increases by £13320. An outcome of interest in this scenario is that whilst the spouse maintains her caring commitments, home production activities switch to the farm operator, his labour supplied to the farm is reduced and labour is hired in.

Table 7 Changes in Farm Family Characteristics[1]

Optimal Dairy System	*Column 1* Average Household[2]	*Column 2* Group A Household[2]	*Column 3* Group A Household[2] with Spouse off-farm wage @ £15/hr[2]
Dairy Cows (hd)	70 S7[3]	70 S7[3]	70 S7[3]
Dairy Heifer (hd)	36	36	36
Spring Barley (ha)	2	2	2
Hire Farm Labour (hrs)	-	-	1019
Farmer – farm (hrs)	4,310	4,310	3,291
Farmer – home production (hrs)	1	678	1,697
Farmer – caring (hrs)	-	-	-
Spouse – farm (hrs)	-	-	-
Spouse – home production (hrs)	1,733	1,019	-
Spouse – caring (hrs)	1,711	4,000	4,000
Spouse – employment off-farm (hrs)	440	767	1,786
Farm Profit and Off farm Income (£)	50,301	53,109	63,621

1. All model simulations assume a milk price of 20 ppl.
2. All other model parameters are re-set to baseline values.
3. S7 = spring-calving system with grass silage and 7,000 lt. yields.

Discussion

In this paper we have shown how profit maximizing whole-farm models can play a decision support role in helping farmers to choose their best business strategy. Pannell (1996) suggests that whole-farm mathematical modeling can be employed in the areas of research prioritization, extension, policy analysis, education and the provision of a useful database. In the case of extension, it is argued that these models are likely to be too big, detailed and cumbersome to be the best tool for use by farmers or even for direct one-on-one use by farm advisers. Simpler spreadsheet-based tools will often be much more appropriate for both these purposes. Nevertheless, profit maximizing whole-farm models are valuable for identifying the strategies that should be examined in the spreadsheets. These strategies will most often relate to novel technologies or practices which farmers may be considering, rather than to the standard year-to-year decisions with which farmers are most adept. It is clear that farmers often cease to need computerized decision aids once a decision becomes routine (McCown, 2002). Investigating issues associated with technology choice are thought to be particularly important given the importance of technology in explaining economic growth and because this area of economic theory has been largely neglected in recent years (Allen, 2000).

Agricultural science research generates a lot of empirical information on the physical relationships associated with different agricultural technologies. However, this valuable information is often not evaluated from an economic point of view in a whole farm context. There are many reasons why cooperative work between agricultural scientists and economists is difficult, nevertheless, it is increasingly important given public concerns regarding the impact of modern agricultural technology (Mullen, 1996). This paper represents such interdisciplinary work, in that data generated by agricultural scientists on the physical relationships associated with various milk production technologies have been utilized in a profit maximizing whole-farm model to identify optimal farm business strategies. There is a clear need for an independent analysis of this type given the many commercial interests that attempt to influence dairy farmers in their choice of production and marketing strategies (Valencia and Anderson, 2000).

The specific results from this particular implementation of the model indicates that the optimal dairy system for most Northern Ireland dairy farms involves a system that is somewhere between the extremes of those systems adopted in the US and NZ. The optimal system here will have a distinct confinement stage like the US, at least during the winter months, but will also borrow techniques from NZ to utilize grazed grass during the summer months. Depending on such things as concentrate prices and seasonal milk pricing, the optimal system can either be a spring, autumn or non-seasonal calving system (calving date appears to be relatively unimportant), but it is always likely to be a moderate output system. The success of these mixed (housing plus grazing) moderate output systems depends on how well both the housing stage and the grazing stage is managed. Therefore, to remain competitive in a global market, the dairy industry must relentlessly improve efficiency in all parts of the system. That is, such things as grass productivity, silage quality, grass utilization under grazing, diet formulation, herd genetics, cow fertility, etc., all matter, and must all be continually examined to see whether improvements in these individual factors can be made which would improve the productivity of the whole system. The model reported in this paper has been used for: (1) direct industry advice – i.e. research reports, bulletins and farmers' meetings; (2) higher level strategic advice to the advisory service in Northern Ireland - i.e. CAFRE dairy advisor training days and input into development of a demonstration herd; and (3) informing long term scientific research programs - e.g. used to inform the future development of indices of total economic merit.

Incorporating farm operators and their spouses time allocation, (on and off-farm labour as well as home production and caring), into a profit maximizing model adds to the model's ability to not only test the robustness of the various farming system but also robustness in relation to incorporating time-use decisions made from the farm household perspective, by the farm operator and spouse. The results highlight the significant time spent by dairy farm operators, particularly those with young families, working on farm. Alongside this, spouse's undertakes the majority of the home production and caring roles within the household. In addition, allocation of time to farm work by farm males is usually seven days week with vey few holidays; this can also affect farm family lifestyles and well being. Although the model results are robust across the range of dairy systems the demands on households' members time particularly at key moments within the household lifecycle can have implications for business decisions in relation to how the farm is managed; i.e. to free up time for increased caring and home production farm operators may choose to reduce the overall number of dairy cows. In addition, changes in market price for milk (pence per litre) may result in a reallocation of labour to activities both paid and unpaid by farm operator and spouse. Although this research presents an initial attempt to incorporate household time-use into a profit maximizing model these preliminary findings reinforce the need to understand farmers' decisions in the context of the farm household and not just the farm business.

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