A trade-off analysis model for the pig to pork supply chain in Scotland

Short Description

Scotland's pork sector is under financial pressure. This report presents a model that could help policymakers to assess the different possibilities to improve the producers' situation. The model can be used to approximate the impact of changes in variables such as input prices or output prices on the level of Scottish pork production.

Due to the lack of suitable time series data, it uses mathematical programming tools to model farmers' decisions on the number of pigs to be finished. The model is calibrated using production data from the Scottish Government and cost estimates by Scotland's Rural College (SRUC).

This is one of three linked reports on different aspects of the high value pork market. The others examine attributes for which consumers appear willing to pay and provide insights into some of the challenges that enterprises serving this market face. Highlighting where efficiencies can be made in producing pork and adding value to the final product could improve the resilience of farmers and smaller, independent processors and retailers, and hence of Scotland's rural economy.

Directory of Expertise

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Stage

Ongoing

Purpose

Producers' participation in the Scottish pork sector has decreased in recent years, due to financial pressures on sale and export prices and increasing input costs, notably for ingredients, energy, and wages. This research, which is part of the project Costs and opportunities for Scottish products with higher value status, aimed to assist the sector by formulating a model that can approximate the short term impact of changes in variables such as input prices on the level of Scottish pork production.

This research had three objectives:

1. Examine producers' views on issues affecting Scotland's higher value pork sector;
2. Analyse consumers' willingness to pay for higher value Scottish pork products;
3. Produce a trade-off analysis model for the pig to pork supply chain in Scotland (the subject of this report).

A difficulty with developing a model for a small productive sector such as pork is that the necessary data are not available over a long enough time period to enable the formulation of an econometric model. An alternative approach is to use positive mathematical programming (PMP), as developed by Richard Howitt (1995). PMP allows the explicit modelling of production decisions, including constraints (e.g. production quotas).

This approach has an important advantage over the process of reproducing an observed result (e.g., land allocation or how many animals to finish) using a linear programming model. It is common to find, after formulating a linear model, that the model-predicted allocation differs significantly from the observed one. So, the model cannot be used for policy simulation. Therefore, one is forced to over-constrain the model by adding restrictions that reproduce the observed results. The problem with this approach is that the over-constrained model becomes rigid to changes in the model parameters (e.g., prices and costs) and predicts no or very small changes in the results. The PMP

approach, instead of adding constraints to the model, modifies the objective function by adding parameters that make the problem non-linear (in most cases quadratic), which allows us to calibrate those parameters such that the model reproduces the observed results without additional constraints. Once the model has been calibrated it can be used to measure the impact of increases of output prices or changes in input prices on the production of pork and also the effect that these have on business profitability.

Results

Two approaches are typical in positive mathematical programming (PMP):

- to calibrate the cost function, useful when there is little information about costs, or
- to calibrate the revenue side (in most agricultural production models the calibration is done on average yields, e.g., for crops, milk or animal weights).

We calibrated animal weights because this allows us to simulate changes in variable costs. It is important to note that the parameters of the yield equations only have the objective of reproducing the observed allocation or production; their particular value can reflect many things such as changes in quality. For instance, an increase in the number of animals sent to abattoirs may imply a need to consider as acceptable animals that do not have the right weight.

The calibrated parameters can also be modified for simulation purposes, although for short term simulations probably it is a better choice to keep them constant and based on the most recent data.

Three data sources were used to calibrate the model:

- The different outputs and prices are from the "Economic Report on Scottish Agriculture", 2020 (latest edition);
- Scottish Government slaughtering survey;
- The variable costs from SAC's Farm Management Handbooks.

The below expression provides the supply for animals to be finished (fed a specific diet by farmers to ready them for slaughter). Note that it can be complemented with a demand function (the so-called derived demand function, which comes from processors) for animals to be finished. Also note that if a demand function is added to the model, the output price becomes endogenous (i.e., the output price is determined within the model).

$$\underset{C_i}{\text{Max}}\ \pi = \sum_{i=1}^{2} P_i\left(\delta_i - \alpha_i C_i\right)C_i - v_i C_i$$

s.t.

$$C_1 \le \overline{C}_1$$

$$C_2 \le \overline{C}_2$$

Price paid for finished animal

Average weight

Finished animals

Average cost per animal

Figures 1 to 4 present the model calibration results and its use for simulation. The calibration process was implemented using Visual Basic for Applications (VBA) interacting with MS Excel Solver, which can optimise simple non-linear models such as a quadratic problem.

Figures 1 to 4 present the different stages of the calibration process, which consist of solving the linear programming model subject to the calibration constraints, which force the model to reproduce the observed animal allocation (*Figure 1*); followed by the formulation of a quadratic programming model (second stage, *Figure 2*) and formulation of the supply simulation model (third stage, *Figure 3*). As mentioned, it is possible to close the model by adding a demand side (fourth stage, *Figure 4*), in which case the output price becomes endogenous.

Figure 1: Calibration – First stage (linear programming model)

Scotland - Pigs finishing model								
Information	**Sows and Boars**	**Clean pigs**						
Price (£/tonne)	413.2	1,486.4						
Variable cost (£ per head)	49.87	49.87						
Average weight (tonnes/head)	0.140	0.079						
Observed slaughter ('000 heads)	15.1	342.3						
	Available Animals	**Animals Slaugthered**	**Extra Animals**	**Dual Prices**			**Sows and Boars**	**Clean pigs**
Sows and boars	18.5	15.1	3.4	0.00			1	0
Clean pigs	1,002.9	342.3	660.6	0.00			0	1
Sows and boars	15.1	15.1	0.0	8.13			1	0
Clean pigs	342.3	342.3	0.0	68.07			0	1
Perturbation	0			**Finished animals ('000)**			15.1	342.3
				Total gross margin ('000 £)			23,422.58	
				Gross margin per activity ('000 £)				
				Sows and boars			122.90	
				Clean pigs			23,299.68	

Figure 2: Calibration – Second stage (quadratic programming model)

Positive mathematical programming problem								
	Available Animals	Animals Slaugthered	Extra Animals	Dual Prices			Sows and Boars	Clean pigs
Sows and boars	18.5	15.1	3.4	0.00			1	0
Clean pigs	1,002.9	342.3	660.6	0.00			0	1
New parameters of the calibrated weight function				**Finished animals ('000)**			15.1	342.3
Sows and boars								
α_0	0.00130			**Total gross margin ('000 £)**			23,422.58	
δ_0	0.16005							
Clean pigs				**Gross margin per activity ('000 £)**				
α_1	0.00013			Sows and boars			122.90	
δ_1	0.12514			Clean pigs			23,299.68	

Figure 3: Final supply model (for simulation)

Scotland - Pigs finishing model (simulation module)								
Information	**Sows and Boars**	**Clean pigs**						
Price (£/tonne)	413.2	1790.8						
Variable cost (£ per head)	49.87	87.4						
	Available Animals	**Animals Slaugthered**	**Extra Animals**	**Dual Prices**			**Sows and Boars**	**Clean pigs**
Sows and boars	18.5	15.1	3.4	0.00			1	0
Clean pigs	1,002.9	285.3	717.6	0.00			0	1
New parameters of the calibrated yield function				**Finished animals ('000)**			15.1	285.3
Sows and boars								
α_0	0.00130			**Average weight**			0.140	0.087
δ_0	0.16005							
Clean pigs				**Total gross margin ('000 £)**			19,627.88	
α_1	0.00013							
δ_1	0.12514			**Gross margin per activity ('000 £)**				
				Sows and boars			122.90	
				Clean pigs			19,504.98	

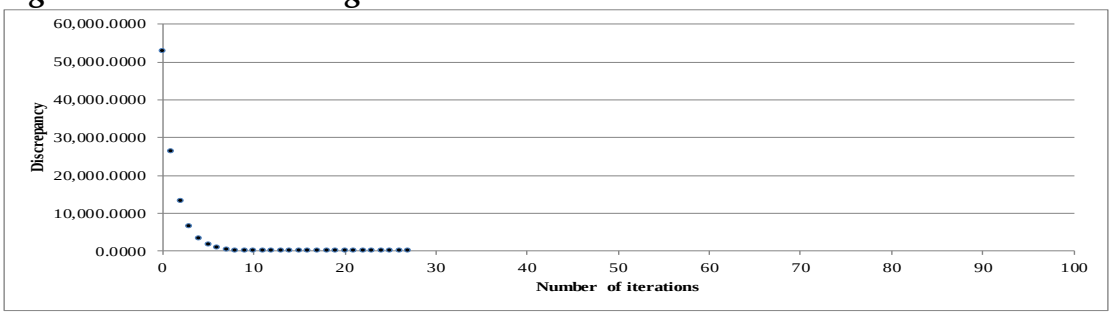
Figure 4: Demand model (for simulation) and equilibrium

Demand functions		
Information	**Sows and Boars**	**Clean pigs**
Intercept	6000.00	100000.00
Slope	14.52	67.26

Equilibrium values		
Information	**Sows and Boars**	**Clean pigs**
Quantities ('000 tonnes)	2.12	27.16
Prices (£/tonne)	413.2	1,486.4
Finished animals ('000 heads)	15.1	342.3
Average weight (tonnes/head)	0.140	0.079

Figure 5 shows the convergence to the equilibrium when the supply and demand are solved simultaneously.

Figure 5: Model's convergence to the solution



Benefits

The benefits of developing this model are illustrated in *Table 1*. It presents the results of a simulation using only the supply part of the model, which consisted of the effects of changes in the cost of production and output prices - considering the model calibrated up to 2019 - and simulated based on prices and costs up to 2022. *Table 1* shows that output prices not only change the total output but also the weight of the delivered animals. The effect of increases of variable costs brings a reduction in the total number of slaughtered animals and a slight increase in the weight. Nevertheless, the increase in costs results in a decrease in the produced output (i.e. quantities).

Table 1: Results from simulating the calibrated model

	2019 (B)	2020	2021	2022
Clean pig prices (£/tonne)				
Quantities ('000 tonnes)	27.2	27.5	27.2	27.8
Prices (£/tonne)	1486.4	1606.0	1499.0	1790.8
Finished animals ('000 heads)	342.3	351.6	343.4	363.6
Average weight (tonnes/head)	0.079	0.078	0.079	0.076
Variable cost (£ per head)	49.9	56.2	62.8	87.4
Quantities ('000 tonnes)	27.2	26.6	25.9	22.8
Prices (£/tonne)	1486.4	1486.4	1486.4	1486.4
Finished animals ('000 heads)	342.3	326.4	309.8	248.0
Average weight (tonnes/head)	0.079	0.081	0.084	0.092
Both changes				
Quantities ('000 tonnes)	27.2	27.0	26.0	24.8
Prices (£/tonne)	1486.4	1606.0	1499.0	1790.8
Finished animals ('000 heads)	342.3	336.9	311.1	285.3
Average weight (tonnes/head)	0.079	0.080	0.084	0.087

This model can therefore approximate the short term impact of changes in variables such as input prices on the level of Scottish pork production. This, in

turn, can help participants in the pork sector to assess the trade-offs involved in pork production. Highlighting where efficiencies can be made in producing pork and adding value to the final product could improve the resilience of farmers and smaller, independent processors and retailers, and hence of Scotland's rural economy.

Project Partners

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