A SECTORAL MODEL FOR ANALYZING ALTERNATIVE TECHNOLOGIES IN PIG FARMING

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Abstract

This paper develops a demand-augmented positive mathematical programming model to analyze the relationship between environmental pollution from animal manure, manure polcies and different pork production systems in the Netherlands. The model features substitution of conventional and alternative pork from the demand side and endogenous manure prices. It is found that policies that put restrictions on environmental pollution from manure decreases the conventional pork production systems, but increases organic pork production systems. The latter is considered an improved system from both an animal welfare and environmental point of view.

Key words: societal concerns, Positive mathematical programming, pork, markets, policies.

1. Introduction

It is well recognized that pork producers in Western Europe increasingly encounter a variety of societal concerns about pork and pork production. The unbalanced focus on production costs and low consumer prices in the past, have resulted in intensive and large-scale production systems based on cheap and imported feedstuffs. Resulting manure and nutrients surpluses on farm level raised concerns of environmental pollution. Other concerns related to the pork production system are safety and healthiness of pork and animal welfare (Kanis *et al.*, 2003).

Changes in the Common Agricultural Policy (CAP) of the EU as Agenda 2000 and CAP Reform 2003 are also enforced by increased public concerns regarding negative externalities of agricultural production in general. Given the wide range of public concerns of citizens and consumers as mentioned by Kanis *et al.* (2003), it can be expected that the process of CAP reform towards decoupling of direct payments and stimulation of extensive production methods will continue. From the literature it can be found that adaptations of the pork production system such that it better satisfies environmental and animal welfare requirements wanted by consumers and citizens, are feasible. However, most of these adaptations can only be carried out at the cost of the present low consumer prices. It is well known that a high price of pork is also a concern for consumers and will affect their purchasing behavior.

Given these public concerns and their increased effect on policy makers, it is of importance for the agricultural economics profession to take these new challenges and develop appropriate analytical tools. This is not an easy matter to deal with existing tools and there is a need to adapt existing tools like positive mathematical programming (PMP) models to address and study these new challenges. Sometimes some of these new challenges are not easily measurable and require the use of alternative methodologies. For instance, take the case of non-market goods like environmental pollution associated with manure or goods that are hardly purchased by consumers like alternative and more expensive pork.

A combined interdisciplinary initiative involving French and Dutch researchers has been initiated for a study of different aspects of the pork production chain (de Greef *et al.*, 2000). One research task was to develop a model capable of assessing the economic and environmental consequences of existing and alternative pork production systems in a wider economic context. As part of this researh effort, a demand-augmented PMP model was developed to capture the substitutability patterns between conventional and alternative pork meats. Moreover, the model also features a technical and economic link to manure emissions, manure surpluses, manure policies and manure markets. The goal of this paper is to get quantitative insights into the economic and environmental consequences of manure policies affecting conventional and alternative pork production systems in the Netherlands at the national and regional level. Mathematical programming can address the relevant environmental

constraints (physical manure application restrictions) explicitely while being consistent at aggregate market level.

In the remaining part of this article we first present the model framework. In section 3 we present some data and scenario's concerning conventional pig production systems and alternative pig production systems in the Netherlands. Section 4 presents the results of the simulations. We end this paper in section 5 with comments and discussion.

2. Model framework

The demand-augmented PMP model framework that will be presented and applied in this paper consists of two components. The first component is the Dutch Regionalised Agricultural Model (DRAM) as described in Helming (2005). The second component is the demand structure for alternative and conventional pork. In section 2.1 we first present the demand structure for alternative pork and conventional pork. In section 2.2. we shortly discuss the DRAM model. In section 2.3 we discuss the calibration of the two demand functions for pork and the activity based quadratic costs function in DRAM. In section 2.4 special attention is given to the estimation of the elasticity of substitution between conventional and alternative pork. The elasticity of substitution is the key parameter along the total elasticity of the demand for pork.

2.1 Modelling the demand for alternative and conventional pork

In this study alternative and conventional pigs are considered as different products, which may partly substitute for each other. The demand functions of alternative and conventional pigs influence each other through the elasticity of substitution. This subsection relies heavily on Lehtonen (2001) with, however, some adjustments.

In the neo-classical theory of consumer behaviour demand functions are obtained when the utility function (1) (summed over all products) is maximised relative to budget constraint (2), i.e. the money available for all food purchases E considered to be given.

$$U(Q_0, Q_1, Q_2) = Q_0 + a_1 Q_1 + a_2 Q_2 - \frac{1}{2}(b_1 Q_1^2 + b_2 Q_2^2 + 2kQ_1 Q_2) \qquad (1)$$

subject to the following income constraint:

$$Q_0 + P_1 Q_1 + P_2 Q_2 \leq E \qquad (2)$$

where Q_1 is the consumption of alternative pigs, Q_2 is the consumption of conventional pigs, Q_0 is viewed as a composite good gathering all the other goods but goods 1 and 2. P_1 is the price of conventional pigs and P_2 is the price of alternative pigs. a_1, a_2, b_1, b_2 and k are parameters to be calculated.

If we assume that Q_0 is the numeraire (equal to unity), then we can formulate first-order conditions which result in linear inverse demand functions for goods 1 and 2 (i.e. alternative and conventional pork). Let us derive these first order conditions:

$$Z = Q_0 + a_1 Q_1 + a_2 Q_2 - \frac{1}{2}(b_1 Q_1^2 + b_2 Q_2^2 + 2kQ_1 Q_2) + \lambda(R - Q_0 - P_1 Q_1 - P_2 Q_2) \qquad (3)$$

Where λ is the Lagrange multiplier or the marginal utility of income.

The first order conditions are:

$$\frac{\partial Z}{\partial Q_0} = 1 - \lambda = 0 \qquad (4)$$

$$\frac{\partial Z}{\partial Q_1} = a_1 - b_1 Q_1 - kQ_2 - \lambda P_1 = 0 \quad (5)$$

$$\frac{\partial Z}{\partial Q_2} = a_2 - b_2 Q_2 - kQ_1 - \lambda P_2 = 0 \quad (6)$$

$$\frac{\partial Z}{\partial \lambda} = (R - Q_0 - P_1 Q_1 - P_2 Q_2) = 0 \quad (7)$$

Substituting λ by its new value in equations (5) and (6) yields, after some manipulations and rearrangements, the following inverse demand relationships for Q_1 and Q_2:

$$P_1 = a_1 - b_1 Q_1 - kQ_2 \quad (8)$$

$$P_2 = a_2 - kQ_1 - b_2 Q_2 \quad (9)$$

Then inverting equations (8) and (9) results in the linear demand functions for conventional and alternative pork.

$$Q_1 = A_1 - B_1 P_1 + KP_2 \quad (10)$$

$$Q_2 = A_2 + KP_1 - B_2 P_2 \quad (11)$$

where A_1, A_2, B_1, B_2 and K are parameters linked to those of the corresponding demand functions for conventional and alternative pork[1].

Implementing these linear demand functions for conventional and alternative pork requires to estimate the parameters of the utility function and to obtain quantitative knowledge on the response of Dutch consumers to prices of conventional and alternative porks. This is addressed further down in this paper.

2.2 the DRAM model

DRAM can be defined as a comparative static, partial equilibrium, regionalized PMP model of the Dutch agricultural sector with environmental aspects (Helming, 2005). In DRAM every region is treated as one representative farm. The regions that are considered in DRAM are presented in appendix I. Within each of the fourteen regions, thirteen arable crop activities (including vegetables in the open and flower bulb activities), two roughage crop activities, one non-food activity, seven intensive livestock activities, including beef cattle and fattening calves, and nine dairy cow activities are distinguished. For each region, the activities produce 25 marketable or final outputs (including one byproduct) and 24 intra-sectorally produced inputs, including 16 different types of animal manure from different types of animals, 6 different types of young animals and 2 types of roughage (grass and fodder maize). Intra-sectorally produced inputs are outputs of agricultural activities that are used as an input in DRAM. On the input side DRAM includes 12 variable inputs, including 7 different types of concentrates for different types of animals. Agricultural inputs and outputs are used and produced by agricultural activities. DRAM describes 32 agricultural activities, with technical (input-output) and economic variables and parameters differentiated per region as far as is possible given data limitations.

[1] See expressions (1.1) in appendix II for these links between the parameters of the demand functions and those of the price inverse relationships.

Objective function

It is assumed that producers and consumers maximize profit and utility respectively. Moreover, it is assumed that markets are perfectly competitive. The objective function is written as follows:

$$\begin{aligned}
\max Z = & \overbrace{\sum_{y}\sum_{r}(\omega_{yr} - 0.5\varepsilon_{yr}Q_{yr})Q_{yr}}^{1} - \overbrace{\sum_{i}\sum_{r}(kk_{ir} + \alpha_{ir}X_{ir} + 0.5\beta_{ir}X_{ir}^{2})}^{2} \\
& - \overbrace{\sum_{i}\sum_{f}\sum_{r} p_{fr}F_{ifr}}^{3} + \overbrace{\sum_{i}\sum_{r} prem_{ir}X_{ir}}^{4} - \overbrace{\sum_{i}\sum_{a}\sum_{r} c_{iar}A_{iar}}^{5} \\
& + \overbrace{\sum_{z}\sum_{r} p_{zr}^{e}E_{zr}}^{6} - \overbrace{\sum_{z}\sum_{r} p_{zr}^{i}M_{zr}}^{7} - \overbrace{\sum_{a}\sum_{r} p_{a}^{g}G_{ar}}^{8} \\
& - \overbrace{\sum_{z}\sum_{r}\sum_{r'}(d_{rr'}vc_{z} + fc_{z})T_{zrr'}}^{9}
\end{aligned} \tag{12}$$

$$Q_{yr}, X_{ir}, F_{ifr}, A_{iar}, E_{zr}, M_{zr}, G_{ar}, T_{zrr'} \geq 0$$

Most indices used in objective function (12) are elements of subsets of sets S^r, S^i, S^j. and S^k. These sets refer to the set of regions, activities, netputs (inputs and outputs) and fixed inputs respectively. The indices in objective function (12) are defined as follows, *r* regions where $r \in S^r$, *i* activities where $i \in S^i$, *d* dairy cow activities where $d \in S^d$ and $S^d \subset S^i$, *y* outputs, excluding young animals, roughage and manure where $y \in S^y$ and $S^y \subset S^j$, *l* inputs, excluding young animals, roughage, manure and nutrients (nitrogen (N) and phosphorus (P)) from animal manure and mineral fertilizers where $l \in S^l$ and $S^l \subset S^j$, *f* nutrients (nitrogen (N) and phosphorus (P)) from animal manure and mineral fertilizers where $f \in S^f$ and $S^f \subset S^j$, *z* intra-sectorally produced inputs young animals, roughage and manure where $z \in S^z$ and $S^z \subset S^j$, *a* represents different types of animal manure where $a \in S^a$ and $S^a \subset S^j$. The endogenous variables, written with upper case and the exogenous variables, written with lower case are defined as follows:

Z = total surplus (producer surplus plus consumer surplus) (1000 €)
Q_{yr} = total (domestic and export) demand of agricultural product *y* in region *r* (1000 tonnes)
X_{ir} = agricultural activity *i* in region *r* (1000 ha; 1000 head)
M_{zr} = import of intra-sectorally produced input *z* in region *r (1000 head, 1000 m³; 1000 kVEM[2])*
E_{zr} = export of intra-sectorally produced input *z* in region *r (1000 head;1000 m³;1000 kVEM)*
$T_{zrr'}$ = transport of intra-sectorally produced input *z* from region *r* to region *r' (1000 m³; 1000 head)*
A_{iar} = application of animal manure *a* to activity *i* in region *r (1000 m³)*
F_{ifr} = application of nutrients from mineral fertilizer *f* to activity *i* in region *r (1000 kg)*
G_{ar} = processing of animal manure *a* in region *r (1000 m³)*
p_{fr} = price of mineral fertilizer *f* in region *r* (€ per kg)

[2] VEM (Voeder Eenheid Melk, fodder unit milk) is a Dutch measure for the amount of energy in feed products: 1VEM = 6.9 kJ Net Energy for Lactation.

$prem_{ir}$ = EU direct payment for activity *i* in region *r* (€ per ha; € per head)

p_a^g = costs of large scale processing of animal manure type *a* (€ per m^3)

p_{zr}^i = import price of intra sectorally produced input *z* in region *r* (€ per head; € per m^3; € per kVEM)

p_{zr}^e = export price of intra sectorally produced input *z* in region *r* (€ per head; € per m^3; € per kVEM)

vc_z = variable transportation costs of intra sectorally produced input *z* (€ per km per m^3; € per km per head)

fc_z = fixed transportation costs of intra sectorally produced input *z* (€ per m^3; € per head)

c_{iar} = application costs of animal manure *a* to activity *i* in region *r* (€ per m^3)

ω_{yr} And ε_{yr} are parameters of the consumers utility function and kk_{ir}, α_{ir} and β_{ir} are parameters of the producers costs function.

Balances of final products, intra-sectorally produced inputs and fixed inputs

Variables $Q_{yr}, X_{ir}, F_{ifr}, A_{iar}, E_{zr}, M_{zr}, G_{ar}$ and $T_{zrr'}$ are elements of different balances for final products and intra-sectorally produced inputs as used and produced by agricultural activities (Helming, 2005). Agricultural production is limited by the availability of fixed inputs. Availability of land and sugar quota is modeled at the regional level. Quota for milk and starch potato are modeled at the national level. It is assumed that labor and capital are not restrictive at the agricultural market level.

Of special importance in this paper are the manure balances per type of manure.

$$-\overbrace{\sum_i \gamma_{iar}\delta_{ir}X_{ir}}^{1} + \overbrace{\sum_i A_{iar}}^{2} + \overbrace{G_{ar}}^{3} - \overbrace{M_{ar}}^{4} + \overbrace{E_{ar}}^{5} - \overbrace{\sum_{r'} T_{ar'r} + \sum_{r'} T_{arr'}}^{6} = 0 \qquad \forall a, r \qquad \left[\pi_{ar}^4\right] \qquad (13)$$

Manure production is considered a by-product from livestock production. That is why equation (13) is presented as equality rather than an in-equality. The coefficient δ_{ir} in equation (13) represents excretion of manure in animal sheds as a fraction of total excretion per animal per year and π_{ar}^4 equals the shadow price of animal manure. These shadow prices of manure are implicit demand prices as they reflect the amount by which welfare would increase with one more unit of manure application in region *r* (Feinerman et al., 2004). Conceptually the model of manure demand in DRAM can be compared with the conceptual model presented by Feinerman et al., (2004). Shadow prices of manure in DRAM are a function of the (shadow) prices of nutrients, the nutrients content of manure, the workability of nutrients in manure, manure application costs, technical manure application restrictions and manure policies. The fertilization balances determine shadow prices of nutrients. Fertilization requirements of the crops can be met by the use of nutrients from animal manure and by nutrients from mineral fertilizer (Helming, 2005).

Incorporating the demand functions for conventional and alternative pork

To incorporate the pork utility function into the objective function the objective function is rewritten as follows:

$$
\begin{aligned}
\max Z = & \overbrace{\sum_{y1}\sum_{r}(\omega_{y1r} - 0.5\varepsilon_{y1r}Q_{y1r})Q_{y1r}}^{1} + \overbrace{\sum_{r}(b1_{y2} - 0.5b2_{y2}Q_{y2r})Q_{y2r}}^{2} \\
& \overbrace{\sum_{r}(b1_{y3} - 0.5b2_{y3}Q_{y3r})Q_{y3r}}^{3} - \overbrace{\sum_{r}kQ_{y2r}Q_{y3r}}^{4} - \overbrace{\sum_{i}\sum_{r}(kk_{ir} + \alpha_{ir}X_{ir} + 0.5\beta_{ir}X_{ir}^{2})}^{5} \\
& - \overbrace{\sum_{i}\sum_{f}\sum_{r}p_{fr}F_{ifr}}^{6} + \overbrace{\sum_{i}\sum_{r}prem_{ir}X_{ir}}^{7} - \overbrace{\sum_{i}\sum_{a}\sum_{r}c_{iar}A_{iar}}^{8} \\
& + \overbrace{\sum_{z}\sum_{r}p_{zr}^{e}E_{zr}}^{9} - \overbrace{\sum_{z}\sum_{r}p_{zr}^{i}M_{zr}}^{10} - \overbrace{\sum_{a}\sum_{r}p_{a}^{g}G_{ar}}^{11} \\
& - \overbrace{\sum_{z}\sum_{r}\sum_{r'}(d_{rr'}vc_{z} + fc_{z})T_{zrr'}}^{12} - \overbrace{\sum_{i}\sum_{r}fc_{i}X_{ir}}^{13}
\end{aligned}
\tag{14}
$$

Where the new indices *y1* outputs, excluding conventional pork, alternative pork, young animals, roughage and manure, *y2* is conventional pork (*y2*=1), *y3* is alternative pork (*y3*=1). Parameters b1, b2 and k are parameters of the pork utility function (see equation 1).

2.3 Calibrating the demand-augmented DRAM model

Cost functions

The fifth element of objective function (14) gives a quadratic variable cost function. Variable costs that are represented are (concentrates, pesticides and other variable inputs). The approach of Positive Mathematical Programming (PMP) is used to calculate the parameters of the cost functions in such a way that the observed activity level is almost exactly reproduced (Howitt, 1995). PMP calibrates the mathematical programming (mp) model in three steps. In the first step the activity levels in the mp model are restricted to observed levels plus a very small number. This gives us a shadow value of the so-called preferred activities (Heckelei, 1997). This shadow value gives the contribution of the activity to the objective function or gross revenue minus shadow prices of fixed inputs included in DRAM. In a more general equilibrium context it can also be seen as the reward to fixed inputs not accounted for in the model or the un-observed costs (Howitt, 1995). The unobserved costs plus the observed costs, initial activity levels and supply elasticities are used to calibrate the parameters of the quadratic costs functions (Helming, 2005). The necessary elasticities are taken from Helming (2005) and assumed equal for both conventional and alternative pork. This means that the own supply elasticities for pork ranges from 2.4 in the sand regions in the Netherlands to 2.1 in other Dutch regions.

Demand functions

The demand functions for conventional and organic pork are characterized by five parameters as shown by expressions (10) and (11) of this paper. Hence, we need five pieces of information or five relationships to generate these parameters. As suggested by Dixit, this can be obtained if we have at our disposals:

- actual prices and quantities of conventional and organic porks (that will provides us with two relationships)
- assumed elasticities. One relationship can be derived if we have the total demand for pork meat. Another relationship is obtained if we know the elasticity of substitution between conventional and organic pork. In addition, it we assume that the utility function containing organic and conventional pork is homothetic, this yields a fifth relationship and the five parameters appearing in expressions (10) and (11) are

identified and computed. This operation which is quite lengthy and cumbersome is explained in Appendix II.

The assumed total price elasticity for pork is equal to –0.75 and borrowed from Mangen and Burrell (2003). The estimation of the elasticity of substitution that is the key parameter along the total elasticity of the demand for pork is now explained.

2.4 Elasticity of substitution between conventional and alternative pork.

Concerning the estimation of the elasticity of substitution between conventional and alternative pork the following arguments are applied:

- There is no available aggregate data on the consumption of alternative pork consumption in the Netherlands over a long time span. We had to rely on survey data conducted as part of the Green Piggery program on responses of Dutch and French consumers to ratios of conventional and organic pork;
- This exercise provides information on an inverse relationship between respondents' shares of purchasing conventional or organic pork and the relative prices. This inverse relationship can be estimated if we assume that the survey repondents' share for conventional pork (denoted by $D_1(p_1,p_2)$can be represented by the following market demand function (Case, 1972, expression (2), p. 207):

$$D_1(p_1, p_2) = \frac{1}{1+\left(\frac{p_1}{mp_2}\right)^{\alpha}} \tag{15}$$

p_1 and p_2 are the prices of conventional and organic pork, respectively. m is a parameter summarizing consumer's attitudes towards conventional pork (Case, 1972), α is a "substitution" parameter between the two categories of pork meat

Respondents' (market) share for organic pork, $D_2(p_1, p_2)$ is equal to 1- $D_1(p_1, p_2)$ and given by

$$D_2(p_1, p_2) = 1 - D_1(p_1, p_2) = 1 - \frac{1}{1+\left(\frac{p_1}{mp_2}\right)^{\alpha}} = \frac{\left(\frac{p_1}{mp_2}\right)^{\alpha}}{1+\left(\frac{p_1}{mp_2}\right)^{\alpha}} \tag{16}$$

If we form now the ratio $\frac{D_1(p_1, p_2)}{D_2(p_1, p_2)}$, we obtain an interesting and familiar relationship given by

$$\frac{D_1(p_1, p_2)}{D_2(p_1, p_2)} = \left(\frac{p_1}{mp_2}\right)^{-\alpha} \tag{17}$$

or

$$\ln\left[\frac{D_1}{D_2}\right] = \alpha \ln(m) - \alpha \ln\left(\frac{p_1}{p_2}\right) \tag{18}$$

If we have observed data on D_1, D_2, p_1 and p_2, we could estimate expression (18) and then derive the elasticity of substitution σ from the parameter α. To do so, we need to implement the following procedure:

- define $D_1(p_1, p_2)$ and $D_2(p_1, p_2)$ as expenditures shares , i.e.

$$D_1 = \frac{p_1 Q_1}{p_1 Q_1 + p_2 Q_2} \text{ and } D_2 = \frac{p_2 Q_2}{p_1 Q_1 + p_2 Q_2}$$

- define the ratio $\frac{D_1(p_1, p_2)}{D_2(p_1, p_2)}$ as

$$\frac{D_1(p_1, p_2)}{D_2(p_1, p_2)} = \frac{p_1 Q_1}{p_2 Q_2} = \left(\frac{p_1}{m p_2}\right)^{-\alpha} \tag{19}$$

$$\ln\left[\frac{p_1 Q_1}{p_2 Q_2}\right] = \alpha \ln(m) - \alpha \ln\left(\frac{p_1}{p_2}\right) \tag{20}$$

To obtain the elasticity of substitution σ, re-express in (20) the ratio $\frac{Q_1}{Q_2}$ as a function of relative prices, which yields the following relationship :

$$\ln\left[\frac{Q_1}{Q_2}\right] = \alpha \ln(m) - \alpha \ln\left(\frac{p_1}{p_2}\right) - \ln\left[\frac{p_1}{p_2}\right] = \alpha \ln(m) - (\alpha - 1)\ln\left[\frac{p_1}{p_2}\right] \tag{21}$$

Then $$\sigma = -\frac{\partial \ln\left[\frac{Q_1}{Q_2}\right]}{\partial \ln\left[\frac{p_1}{p_2}\right]} = \alpha - 1 \tag{22}$$

Expression (21) also is the reduced-form (first order conditions) expression that can be obtained form a two-goods C.E.S. utility function.

The available dataset contains 8 observations (Meuwissen, et al., 2003). Estimation of expression (18) yields the results that are given in table 1. Following expression (22) the elasticity of substitution equals 11.4805. Within the Green Piggery project similar results are obtained for France (Carpentier *et al.*, 2003).

Table 1: Econometric estimate of elasticity of substitution

Expression	intercept	$\ln(\frac{P_1}{P_2})$	Adj. R^2	SE
$\ln\left[\frac{D_1}{D_2}\right]$	-2.0451 (-2.6489)	12.4805 (6.2392)	0.84419	0.8721

Note: *t*-statistics are in parentheses