Economic optimization of pork production-marketing chains: taking in account animal welfare and environmental constraints

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Introduction

Consumers show increasing interest in the quality of the product and the production process, including animal welfare, environmental pollution and food safety issues (Burbee and Kramer, 1985). This creates opportunities for selecting market segments to which more value can be offered through product differentiation. Demands of this type almost entirely concern the upstream farm stages of the so-called Production-Marketing Chain, requiring the transmission of those – changed – consumer preferences to primary stages. Vertical cooperation is considered a promising strategy in this respect. Whereas forward cooperation gives better access to market information, allowing a specific adjustment of product or process characteristics to consumer needs, backward cooperation increases the possibility of obtaining specialized inputs through which final products may be improved or at least distinguished (Porter, 1980). In the Dutch swine industry, the pork chain producing 'Outdoors' pork meat, is an example of a chain that includes consumers demands on animal welfare.

In the Netherlands, the surplus of animal manure causes environmental problems in terms of soil acidification and soil saturation. Major causal factors are considered to be Phosphate, Ammonia and Nitrate. In May 1993, representatives of agribusiness and government reached an agreement on environmental pollution. Targets were set to reduce pollution by agriculture. At the same time, national legislation was prepared that prescribes conditions under which pigs must be kept with respect to their welfare. Both types of agreements will require high future investments of farmers.

Various on-farm measures are available in order to reduce environmental pollution and improve animal welfare. Environmental measures include adaptations of feed types and regimes, housing facilities, and storage and processing of manure. Housing facilities are also considered to affect animal welfare, e.g. the amount of floor space per animal and whether or not animals have access to outdoors facilities outside the barn.

Market demands and government regulations are not static but change over time. A relevant differential advantage of a chain system today, therefore, may be irrelevant in the future. Anticipating future developments, it is interesting to explore how these changes will influence the structure and profitability of chain concepts, especially in case of potentially conflicting issues (e.g. demands involving lower costs, higher animal welfare standards and more environmental friendly systems). Therefore it is important to gain insight into ways to optimize chain concepts at minimal costs under (current and future) constraints of animal welfare and environmental issues.

The objective of this paper is to present and describe the economic effects of factors considered to improve animal welfare throughout the stages of the pork production marketing chain. Potential impact of these factors on environmental pollution, is also taken into consideration. At first, outline and definitions of the production-marketing chain, will be described. Subsequently, an economic chain simulation model is presented, which is used to calculate the costs and benefits of the factors related to animal welfare within the pork production-marketing chain. In the chain model a farrowing stage producing feeder pigs, a fattening stage producing hogs, and a slaughtering stage, are included. Transportation of feeder pigs and hogs between the stages, is also considered. Following the description of the chain simulation model, it is described how animal welfare is taken into account. Factors assumed to affect animal welfare throughout the pork chain, as well as the questionnaire, used to estimate their impact on animal welfare, are described. The questionnaire was created and analyzed using conjoint analysis of multi-attribute parameters (Steenkamp, 1985), enabling an estimation of animal welfare coefficients in terms of both main effects and interactions of the factors considered. The questionnaire was sent to pig welfare experts and representatives of consumer organisations, retailers, and animal welfare advocacy groups. Potential environmental effects of the factors considered, are measured in terms of ammonia emission. Finally, a linear programming model is presented which is used to minimize costs of producing pork products, under various constraints on both animal welfare and environmental pollution criteria.

Chain definitions

Theoretically the successive steps or activities involved in converting raw materials into final products and distributing them to the final user can be subdivided indefinitely (Ikerd and Higgins, 1973; Porter, 1985). However, in defining the boundaries between stages, most authors emphasize technological, functional, geographical and/or economic separability. For instance in Porter's (1985) 'value chain' concept, the relevant 'value-activities' in which a firm is disaggregated, are separated on technological, economic and strategic relevant distinctions. In its turn, the value chain of a firm is embedded in a larger stream of value activities, called the 'value system' (Porter, 1985). The value system also includes the value chains of supplying and buying firms. According to Porter (1985), the appropriate degree of (dis)aggregation of activities depends on their economics and the purpose of analysis. Since this paper is especially concerned with the activities performed within separate farms and agribusiness firms of the pork chain, a stage is described in economic terms. An 'economic' stage can be defined as the combination of activities performed between two adjacent marketing levels, i.e. a saleable product or service exists at the separation between stages (Ikerd and Higgins, 1973). This means that a 'stage' is defined within the boundaries of a firm in a way comparable to Porter's value-chain. The term 'production-marketing chain' is used here to describe the combination of vertically related firms or stages through which a product flows from raw material to final consumption. This is comparable to Porter's value system. As the above definition indicates, an important characteristic of production-marketing chains is that their stages are interlinked vertically. Vertical linkages are relationships between the way supplier or buyer activities are performed and the cost or performance of a firm's activities; and vice versa (Porter, 1985).

Vertical integration can be defined as the combination of two or more stages of a production-marketing chain, under single ownership (Porter, 1980). Compared to regular market exchange, in which stages are coordinated through the functioning of the price system only, vertical integration alludes to internal coordination by one firm having complete control over the integrated neighbouring stages. Incomplete vertical integration or vertical cooperation refers to vertical relationships between two or more adjacent stages without full ownership or control (Porter, 1980) in which the partners fundamentally maintain their independence but for example share information or coordinate pricing. Control is transferred of some, but not all, aspects of production, distribution or marketing. This incomplete shift of control accompanied by maintenance of autonomy distinguishes vertical cooperation from vertical integration. Vertical cooperation is a way of 'broadening scope without broadening the firm' (Porter, 1985).

Material and methods

Economic chain simulation model

Basically the purpose of the chain simulation model is to simulate technical and economic performance of an average - representative - sow farm, fattening farm or slaughterhouse. The farrowing stage in the model produces feeder pigs which are transported to the fattening stage at a live weight of approximately 23 kilogram. At the fattening stage the feeder pigs are grown and finished (hogs). At a live weight of approximately 108 kilogram the finished hogs are transported to the slaughterhouse where they are slaughtered and either sold as a carcass or processed further.

Costs are calculated as opportunity costs, representing the potential benefit that is given up because one application of an asset is chosen over another. The cost calculations are presented at an animal basis, i.e. per feeder pig sold (farrowing stage), per hog sold (fattening stage) and per hog slaughtered and sold (slaughtering stage). With respect to the farrowing and the fattening stage, the efficient scale of operation is based on the number of animals (sows and hogs respectively) that one skilled worker or full time equivalent, can handle within a regular number of working hours per year. Regarding the slaughtering stage it is assumed that the efficient scale of operation equals a slaughter capacity of 300 to 400 pigs slaughtered per hour (Product Board for Livestock and Meat, 1991).

In general four types of variables are distinguished in the model: input variables, variables representing interstage relations, technical output variables, and economic output variables. A variable controlling interstage relations, can be an input variable, requiring an input value of the user, or a technical output variable, calculated by the chain model. A schematic description of the relations between major groups of variables, is presented in *Figure 1*. The model runs with - Dutch - default input values but allows the user to enter data for all input variables considered, and therefore, can be adjusted to individual price and production conditions worldwide. Default values of important input variables are presented in appendix I.

Input variables concern input both on farm lay-out and on technical performance, such as culling and reproduction information in the farrowing stage. The farm lay-out, i.e housing and feeding facility, is related to the labour required for handling the animals in the farm stages. Based on the input values, technical output is calculated. An important technical output variable in the farm stages is the farm scale. Combined with other technical output, the farm scale determines how many pigs can be sold per year. In this way, it effects both the interstage relation between the farrowing stage and the fattening stage, represented by the number of feeder pig suppliers (*Figure 1*), and economic results of the farm. Although no specific interstage relation is defined concerning pig transportation, transportation costs per animal strongly depend on the output of the farm stages, such as the number of pigs that has to be transported per time and the average weight of the animals. As the slaughtering stage performs an important step in matching the supplied hogs to the demand of carcasses and primary parts, demand is an important input variable in this stage, as is the revenue of the various carcasses and parts.

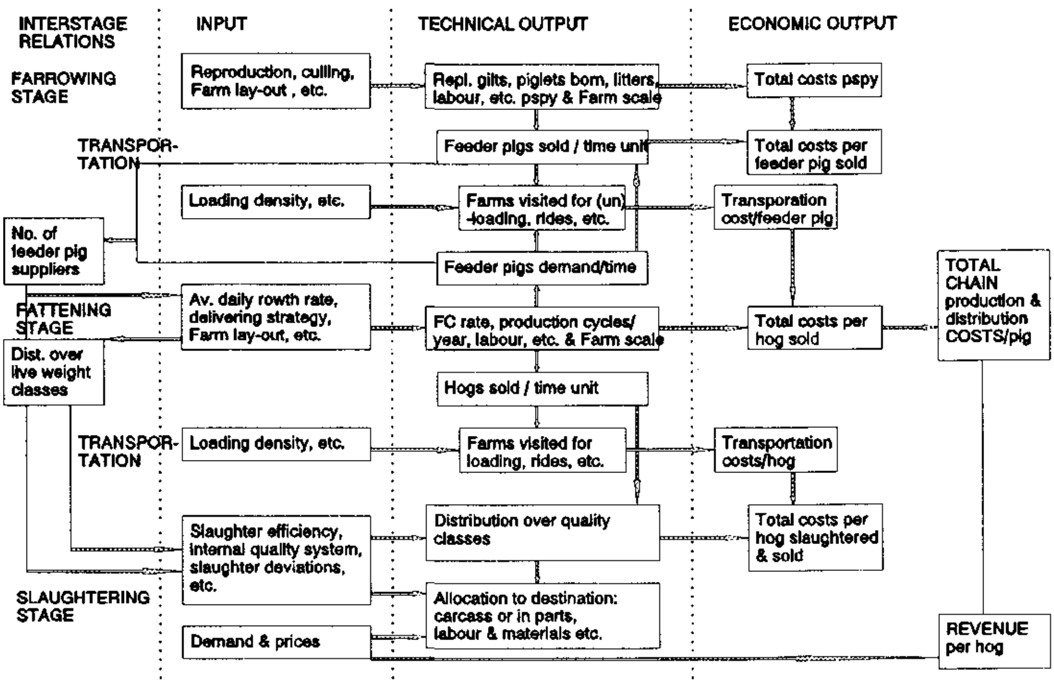

Figure 1. Schematic representation of the economic pork chain simulation model (pspy = per sow per year, FC = Feed Conversion)

Transportation of feeder pigs to the fattening farm and transportation of hogs to the slaughterhouse, are assumed to take place on cost of the fattening stage and the slaughtering stage respectively. Feeder pigs can be delivered to the fattening farm, approximately once per week, as is common in practice. The exact length of this period, however, depends on the delivery schedule of hogs to the slaughterhouse. Based on the loading density during transportation of pigs, the average live weight, and the net transportation surface, the loading capacity of the truck is calculated. Truck loading capacity, occupation rate of the truck and the number of feeder pigs available for transportation, yield the number of farrowing farms that have to be visited to load the truck. The number of feeder pigs needed per time unit at the fattening stage, determines how many farms a transportation truck has to visit for complete unloading. The number of farms visited are related to the time needed for loading and unloading. Moreover, comparison of the number of feeder pigs available for sale per time unit, with the number of feeder pigs needed per time unit in the fattening stage, reveals how many feeder pig suppliers are required. Elbers (1991) found that the number of feeder pigs suppliers of a fattening farm, influenced its productive performance. Both effects on daily growth rate, mortality rate and drug use in the fattening stage, and effects on the prevalence of pathological lesions observed in the slaughtering stage, were quantified.

With respect to the fattening stage, average daily growth rate can be considered a major input variable of the model. The average growth rate is related to the feed conversion ratio, implying a smaller use of feed per kg live weight gain as the growth rate increases. The daily growth rate is assumed to be normally distributed. The delivering strategy is defined by the number of deliveries per production cycle from one compartment, and the relative distribution of hogs over those deliveries. Growth rate, the standard deviation in growth rate and the delivering strategy, are the primary variables used to calculate the distribution of hogs sold over live weight classes, the number of production cycles per year and the occupation rate of hog places. The distribution of saleable hogs over live weight classes is related to the distribution of carcasses over quality classes within the slaughterhouse, as such representing an important interstage relation. Combined with the choice of housing facility and feeding system, the number of production cycles per year is used to calculate the hog farm scale (*Figure 1*).

Transportation of hogs resembles transportation of feeder pigs. The only difference refers to unloading at one place (slaughterhouse) instead of at several fattening farms.

In the slaughtering stage the following processes can be distinguished: supply of hogs, slaughtering, cutting of carcasses into primary parts, and sale and expedition of end-products. The distribution over live weight classes of hogs and the slaughter efficiency, are the primary variables used to determine the relative distribution over quality classes. Carcasses are distributed over the various quality classes by means of the internal quality system, which is based on various combinations of slaughter weight, lean meat percentage and overall body composition. The quality classes determine the processing options of the carcass and therefore, the processing costs and the potential value of a carcass (Figure 1).

To evaluate the consequences of changes in the production or distribution system on costs and benefits along the chain, both costs that vary proportionally with the scale of operation, and costs that remain constant over a specified range of activity, are considered. Since total cost in the last case remain constant, cost per animal varies inversely with changes in scale of operation. Examples of cost components of this type include labour costs (excluding hired labour), costs of buildings and transportation facilities, and overhead costs. Activities that require labour time in direct proportion to the scale of farrowing or fattening, involve common activities such as feeding, cleaning and health care. In the default situation the animals within the farrowing stage are fed automatically. Investments in buildings and equipment per sow place and per hog place are related to the number of places per farm. By increasing the number of places, the investments per place decrease less than proportionally.

Animal Welfare

Public concern about animal welfare and animal rights appears to be increasing in the north-western European countries as well as in the United States of America. While the mood of the general public is difficult to gauge, one indication is a proliferation of advocacy groups dedicated to improving animal welfare. As some of these advocacy groups in the Netherlands are known to carry on successful campaigns, they are assumed to both represent and influence the opinion of various consumer groups.

The purpose of this study is to evaluate the impacts that potentially could occur in the various stages of the pork production-marketing chain, if production systems and tools which address selected animal welfare concerns, are adopted. In order to explore how these concerns may influence production and transportation systems and their costs, one would anticipate on which concerns are important regarding pig welfare, and their degree of importance. Based on literature (e.g. Putten and Elshof, 1978; Ruiterkamp, 1985; Gloor, 1988; Wolbert et al, 1993) and consultation of experts, various factors, described in *Table 1*, are assumed to be related to pig welfare along the pork production-marketing chain. The factors are presented per stage of the chain to which they refer. For each factor the possible values considered, are presented as well.

Mixing a socially stable group of animals may increase fighting behaviour to re-establish a new social order (Scheepens, 1992). However, mixing animals, e.g. during transportation, that have no experience of being placed in socially new groups, is regarded to have a bigger negative impact on their welfare compared to when they have experienced this at an earlier age. Moreover, by grouping pigs according to their live weight and age, variation in market weight can be reduced, increasing profitability of the fattening stage by increasing the number of production cycles per year and reducing the price discounts received due to slaughter weights outside the highest paid range of 75 to 95 kg in the Netherlands (Hoste and Baltussen, 1992).

Moving piglets at weaning from the known environment of the nursery room to an unknown rearing pen, may cause substantial stress (Scheepens, 1992). In general, providing more (concrete) space to pigs, straw for distraction, day-night rhythm of light available and outdoors space, is considered beneficial with respect to the welfare of the pig. Housing non-lactating sows in groups instead of individually, enables them to have social contacts and more freedom of movement. With respect to welfare of the sow, housing in cubicles in often preferred above tethered housing.

Regarding the fattening stage, feeding roughage to hogs is considered to improve their welfare as it supplies stomage contents and distraction. Climatic conditions should provide the hog with a thermo-neutral zone and prevent draft. Using a computer to control climate, may improve climatical conditions.

Table 1. Factors, considered in this study, which are assumed to be related to pig welfare in the various stages of the pork production-marketing chain

Farrowing		*Fattening*	
socially mixing at weaning	Y/N	socially mixing start fattening period	Y/N
weaning age (weeks)	4-6	ventilation automated	Y/N
move at weaning	Y/N	roughage fed	Y/N
concrete:total floor nursery pen (m^2)	0:3.8/4:6.5	concrete:total floor (m^2)	0:0.6/0.4:0.9
group housing non lactating	Y/N[1]	straw available	Y/N
total floor space (m^2) non lactating	1/2.2-1.4/3[2]	light available (lux)	0/20
straw available	Y/N	outdoors space (m^2)	0-1.1
light available (lux)	0/20		
outdoors space (m^2)	0-5		
Transportation		*Slaughtering*	
socially mixed at loading	Y/N	socially mixing	Y/N
handling	rough/quiet	slope loading bridge	>20°/≤20°
loading at more farms	Y/N	resting period (hours)	2/4
loading density (kg/m^2)	300/235	showering	Y/N
ventilation automated	Y/N	stocking density (kg/m^2)	300/235
		handling	rough/quiet
		lay overnight	Y/N

1 In case of individual housing, non-lactating sows can be tethered or be housed in cubicles.
2 The first figure (1 m^2 to 1.4 m^2) relates to individual housing, while the second figure (2.2 m^2 - 3 m^2) relates to group-housing of non-lactating sows.

Removing pigs from a known environment, causes stress and scares the pigs which may not be moved easily then. Rough handling, using electric prodders to force the pigs, may save labour time but cannot be regarded beneficial to the welfare of the animal. Each time, the truck stops to load pigs at another farm, the pigs may start to explore their new environment and start fighting for social order. Moreover, the screaming noises of the new loaded and unknown pigs, may cause additional stress.

High stocking densities as a result of high loading factors, are less preferred with respect to pig welfare. However, too low stocking densities must be avoided also in order to prevent the pigs from falling during transportation. Pigs dislike climbing and descending steep loading bridges. Reducing the angle makes loading much easier for the inexperienced animals, as does a lifting-platform as a loading device attached to the lorry, even more (Putten and Elshof, 1978). Showering the animals during the resting period in the slaughterhouse, has a beneficial effect on hogs by cooling them and reducing fighting behaviour.

Much literature is available on how to measure animal welfare in general, and on the differences in pig welfare in different production systems. Parameters described to measure animal welfare involve physiological, veterinarian and ethological variables. Body temperature, heart beat rate and blood composition, are examples of physiological parameters, while mortality, morbidity and external injuries of the animal, are examples of veterinarian parameters. Ethological parameters relate to the behaviour of the animal, concerning both changed behaviour, inability to express certain behaviours and so on (e.g. see Ruiterkamp (1985) and Gloor (1988)). The problem with this kind of parameters is that different ones are used to measure the various animal welfare related factors. Therefore, the impact of several animal welfare related factors along the stages of the pork chain, may not be measured in a unique parameter, making it impossible to compare and use these factors simultaneously. Moreover, it may be expected that members of animal welfare advocacy groups, consumer groups, and retailers, being the closest to (buying) public opinion, are not acquainted with - the interpretation of - these parameters. Therefore, a questionnaire based on conjoint analysis, is used here to estimate the impact of the various factors, or attributes, on animal welfare, on an interval scale of numbers, ranging from 0 to 100. A comprehensive description of the usage of conjoint analysis to measure consumer preferences to product attributes, can be found in Steenkamp (1985). Production system characteristics are considered external attributes of the pork meat product. Each possible combination of the values of these attributes, a so-called product 'profile', yields a potential new product. Understanding how each of the attributes contributes to the preference of the respondent of the product as a whole, it often is not possible to let the respondents judge all possible profiles (full factorial design), because of the great number of possible profiles. For example, combination of three attributes at three possible values with two attributes at two possible values, would yield $3^3 * 2^2 = 108$ profiles to be judged. Using fractional factorial designs in conjoint analysis (Steenkamp, 1985), enables the researcher to strongly reduce the number of profiles that have to be judged. Moreover, by employing compromise designs it is also possible to take potential interactions into account. Per stage, one questionnaire (case) was developed. To link stage results to results that can be used for the chain as a whole, each respondent was asked to quantify the relative importance of each stage to overall pig welfare throughout the stage. Besides the 8 to 16 profiles needed per stage to estimate the contribution of each welfare related attribute, 3 hold-out profiles were added to each case to test the predictive validity of the estimated coefficients per respondent. The predictive validity can be described as the way in which the scores of new profiles can be predicted correctly, by means of the estimated model coefficients.

The questionnaires were sent to 11 respondents, of which half could be regarded as experts on pig welfare, while the other half represented animal welfare advocacy groups and retailers (denoted as the consumer-related group). As the interests of the animal welfare groups appear to 'evolve' over time, it is expected that their opinions show a greater variance and may differ from the opinions of the experts.

The questionnaires were analyzed using the ANOVA procedure for linear regression of SPSS (Norusis, 1992). The hypothesis that the group of experts would yield significantly different welfare coefficients compared to the consumer-related group, is tested by means of the F-test of ANOVA. The R^2 or correlation coefficients were used as a measure of internal validity of the models estimated. The predictive validity of the models was tested using Chi^2-test.

Linear Programming

In order to explore how increasing levels of animal welfare will interact with costs incurred to achieve those levels in the pork production marketing chain, a linear programming model was developed. The objective of the linear programming model is to minimize costs under various constraints on animal welfare (and environmental issues). The relations between the various models used in the study, is presented in *Figure 2*.

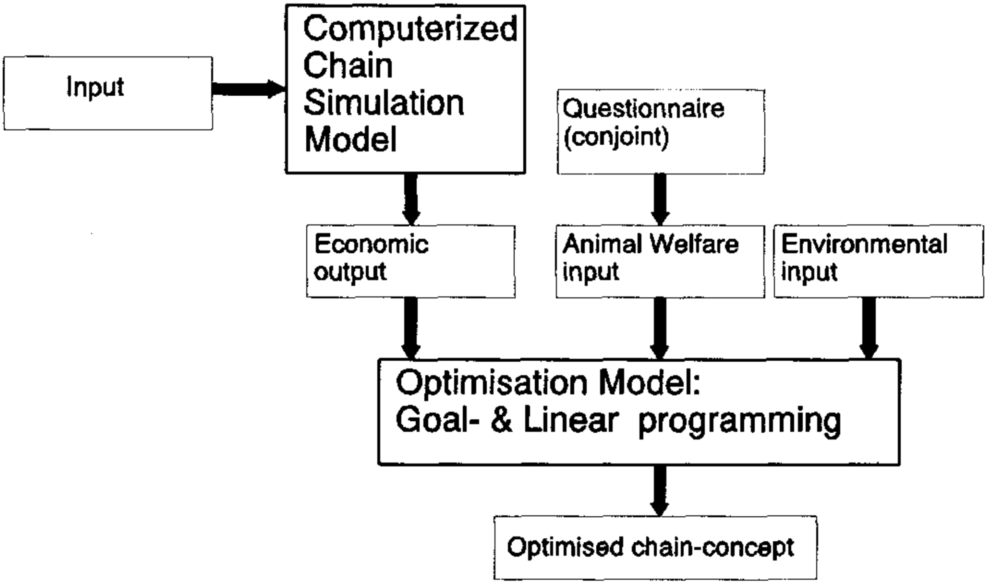

Figure 2. Schematic representation of the overall model structure, linking the chain simulation model to the optimisation model

As is shown in Figure 2, the economic input of the optimisation model is generated as economic output by the pork chain simulation model. In this way, additional costs, incurred by adding an animal welfare related attribute to the chain concept, are calculated taking into account the interstage relations between the various stages. The animal welfare coefficients, representing the relative importance of an attribute to the overall welfare of the pig in the chain, are calculated from the questionnaires, using the conjoint analysis. Environmental input, in terms of ammonia emission, is required from literature. By means of the optimisation model, additional chain production costs per pig, can be minimized taking into account both animal welfare and environmental constraints.

Results

Chain simulation model

With the – Dutch – default values of input variables used in the chain model, sows produce 2.26 litters per year resulting in 20.8 feeder pigs sold per sow per year. Within the fattening stage 2.94 production cycles are realized per year. The integral cost price analysis resulted in production costs per feeder pig sold of Dfl. 118, while the cost price per hog sold equals Dfl. 189. The total production costs per hog sold to the slaughterhouse, therefore, equal Dfl. 307 from farrow-to-finish. Total costs of slaughtering hogs and selling them as either carcasses or in parts ('first cut'), equal Dfl. 49 and Dfl. 63 respectively. The higher costs of processing and selling first cuts instead of carcasses, mainly result from the additional labour time required.

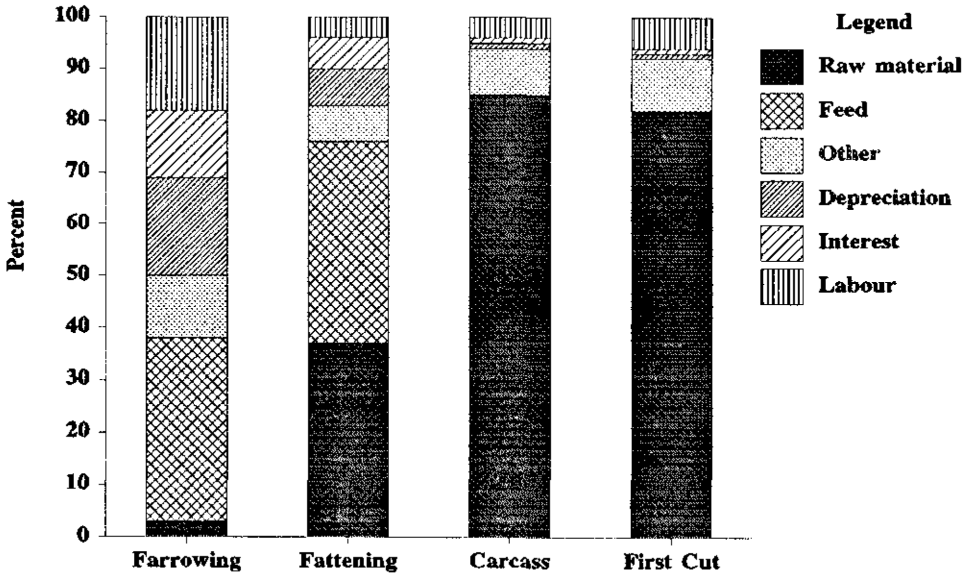

Figure 3. Cost composition of feeder pigs (farrowing stage), hogs (fattening stage), carcasses and first cuts (slaughtering stage)

In *Figure 3*, the distribution of the overall cost price over the various cost components is presented per feeder pig sold, per hog sold and per carcass or first cut sold. Raw material costs included, are based on the average 1992 market prices. As shown in Figure 3, feed costs are the major cost components in both the farrowing and the fattening stage, representing 35% and 39% of the total cost per feeder pig and hog sold, respectively. Excluding the costs of feeder pigs bought in the fattening stage, the feed costs per hog sold, even represent 61% of total production costs. However, the farrowing stage is relatively labour-intensive compared to the more capital-intensive fattening stage. The overall costs of slaughtering and selling hogs, mainly consist of raw material costs. Comparable figures of the composition of slaughtering costs were described by Lorenz (1991), who also mentioned the raw material costs as the major cost component in the slaughtering stage.

In Table 2, the costs coefficients calculated by the chain simulation model, are presented. Cost coefficients are presented on animal basis and represent the extra or marginal costs of changing a variable from the lowest to the highest value considered in the questionnaire (Table 1). For example, when, in the farrowing stage, the weaning age is changed from 4 to 6 weeks, the production costs per pig produced in the chain, increase by Dfl. 12.2. The effect of not socially mixing of piglets at weaning, is assumed to increase the standard deviation in daily growth rate in the fattening stage with 10%. As a result, total production costs per pig, are increased by Dfl. 0.50. Of these costs, 18% was incurred at the fattening stage, 6% at hog transportation, and 76% at slaughtering the hogs and selling them at a lower value. This clearly demonstrates the effect of an interstage relation. Moreover, with respect to cost effects, some attributes are related to each other.

Table 2. Chain costs coefficients (Dfl. per pig) calculated by the chain simulation model for use in the linear programming model

Farrowing		*Fattening*	
no socially mixing at weaning	0.5	no socially mixing start fattening period	0.5
weaning age	12.2	ventilation automated	1.6
move at weaning	1.4	roughage fed	8.5
concrete:total floor nursery	3.3	concrete:total floor	5.5
housing non-lactating[1]	2.2/3.7	straw available	9.5
total floor space non-actating[1]	0.3/0.7	light available	0.2
straw available	6.0	outdoors space	7.3
light available	0.4		
outdoors space	1.9		
Transportation		*Slaughtering*	
no socially mixing at loading	3.49	no socially mixing	0.02
handling	0.09	slope loading bridge	0.04
loading at more farms	2.2	resting period	0.02
loading density	0.7	showering	0.04
ventilation automated	0.05	stocking density	0.01
interaction[2]		handling	1.4
		lay overnight	0.14

1 The first figure relates to individual housing, while the second figure relates to group-housing of non-lactating sows.
2 Interaction between loading density and ventilation.

For example, due to the fact that the available light depends on the area of the pen, adding extra space will also require additional light to meet the desired light (lux) standards. If outdoors space is provided to hogs, the departments have to be build along the central passage of the barn instead of transversely to the passage, implying an increase of total housing costs and higher costs of additional concrete space. As a result, the additional chain production costs per pig, incurred in case all animal welfare related attributes are added, will be higher than the sum of the costs presented in *Table 2*.

Animal welfare

All respondents were asked by phone for their cooperation, before the questionnaire was sent to them. Questionnaires were sent back by 7 of the 11 respondents, resulting in a response rate of 64%. The non-respondents involved one 'expert' and three representatives of animal welfare advocacy groups.

On average, good fits of the estimated models per respondent were obtained. Per attribute, the estimated coefficients varied greatly between respondents. Although the estimated coefficients revealed little consensus between the respondents in general, respondents showed greater concordance with respect to the attributes they regarded most important in each case. When the estimated coefficients per respondent were ranked hierarchically according to their absolute value, it was found that the respondents, on average, rated the factors 'socially mixing', 'housing of non-lactating sows', and 'availability of straw', as the three most important welfare related factors of the farrowing stage. Regarding the fattening stage, in general, the attributes 'straw available', 'light available' and the ratio of 'concrete to total floor space', were judged most relevant to the welfare of hogs, as were 'handling' and 'socially mixing' during transportation and slaughtering.

Table 3. The estimated pig welfare coefficients of a consumer representative and an expert, which were used in the linear programming model.

	consumer repr.	expert		consumer repr.	expert
Farrowing			*Fattening*		
no socially mixing at weaning	1.3	8.6	no socially mixing start	3.2	1.6
weaning age	1	4.7	fattening period		
move at weaning	2.2	0	straw available	10.1	11.4
concrete:total floor nursery	3.3	0	(0.1 kg/pig/day)		
housing non-lactating	3.8	9.2	concrete:total floor	12.9	1.5
total floor space non-lactating	2.3	–2.2	light available (20 lux)	6.5	8.2
straw available	3.0	2.7	ventilation automated	1	0.6
(0.2 kg/pig/day)			roughage fed[1]	5.1	3.8
light available (20 lux)	2.5	1.8	outdoors space (1.1 m^2)	16.1	7.0
outdoors space (5 m^2/sow)	5.6	2.1			
Max. welfare points	24.9	29.1		54.9	34.1
Transportation			*Slaughtering*		
no socially mixed at loading	0.8	5.1	no socially mixing	1.6	3.1
handling	6.0	6.2	slope loading bridge	0.9	2.5
loading at more farms	0.8	2.4	resting period	–1.2	1.5
loading density	1.0	2.2	showering	0.9	1.5
ventilation automated	0.3	0.5	stocking density	1.2	2.3
interaction[2]	1.0	2.7	handling	5.2	3.1
			lay overnight	0.1	0.1
Max. welfare points	9.9	19.1		9.9	14.1
3-way interaction socially mixing	0.4	3.6			

[1] The amount of roughage that had to be fed to hogs was quantified at one tenth of the daily amount of concentrated feed and at 1 kg per hog per day respectively.
[2] Interaction between loading density and ventilation.

Analysis per group of respondents, that is the experts versus the consumer-related group, did not yield a significant difference, implying that the expected contrast between the two groups could not be proved with the data of this study.

When the predictive validity of the estimated models per respondent was tested (Chi[2]) by means of the hold-out profiles, it was found that the predicted values and real values of the hold-out profiles of each case, did not differ significantly for one respondent (= 0.10). With respect to the data of the other respondents, predictive validity in total, was lower. For purpose of illustration, the estimated welfare coefficients based on the data of a respondent out of the consumer-related group and of an expert, are used in the linear programming (LP) model (*Table 3*).

As is shown in Table 3, the welfare coefficients based on the data of the expert and the consumer representative, add up to different maximum welfare points per stage. For example, using the welfare coefficients of the expert would result in a maximum of 34.1 points, in case all the welfare related attributes of the fattening stage were added to the chain concept. In contrary, the coefficients of the consumer representatives, add up to a maximum of 54.9 points. Combined with the - interstage - interaction coefficient, a maximum of 100 points can be realised in case all attributes are included. This holds for the welfare coefficients based on both the expert and the consumer representative.

Optimization: costs and animal welfare

In *Figure 4*, the additional chain production costs per pig sold, are presented, at increasing levels of animal welfare. Both the results based on the welfare coefficients of the expert and the consumer representative (Table 3), are shown.

In case of relatively low levels of animal welfare, the usage of the coefficients of the expert in the LP-model, yields the same desired animal welfare level at lower costs per pig as compared to using the welfare coefficients of the consumer representative. Apparently, the expert has valued the attributes, which require relatively low costs to implement, with more animal welfare points. Examples involve diminishing the slope of the loading bridge at unloading the truck at the slaughterhouse and adding additional light to hogs at the fattening stage. Recall the fact that in the questionnaire, the costs of implementing the attributes were not described. However, as the desired level of animal welfare increases, the difference between expert and consumer representative, in marginal costs per pig necessary to achieve this level, becomes smaller. In fact, at a level of 90 animal welfare points, the costs of the chain concept, incurred by using the coefficients of the expert, are even higher than those incurred in case the coefficients of the consumer representative, are used. Moreover, it is shown in Figure 4, that the additional per pig increase progressively at higher desired levels of animal welfare. The highest additional costs per pig in the

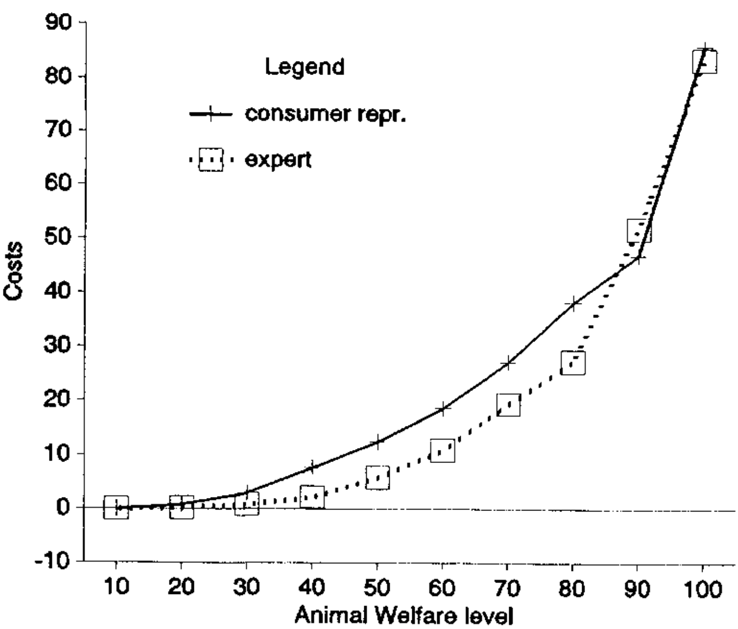

Figure 4. Additional chain production costs per pig sold at increasing levels of animal welfare, using both the animal welfare coefficients of an expert and a consumer representative

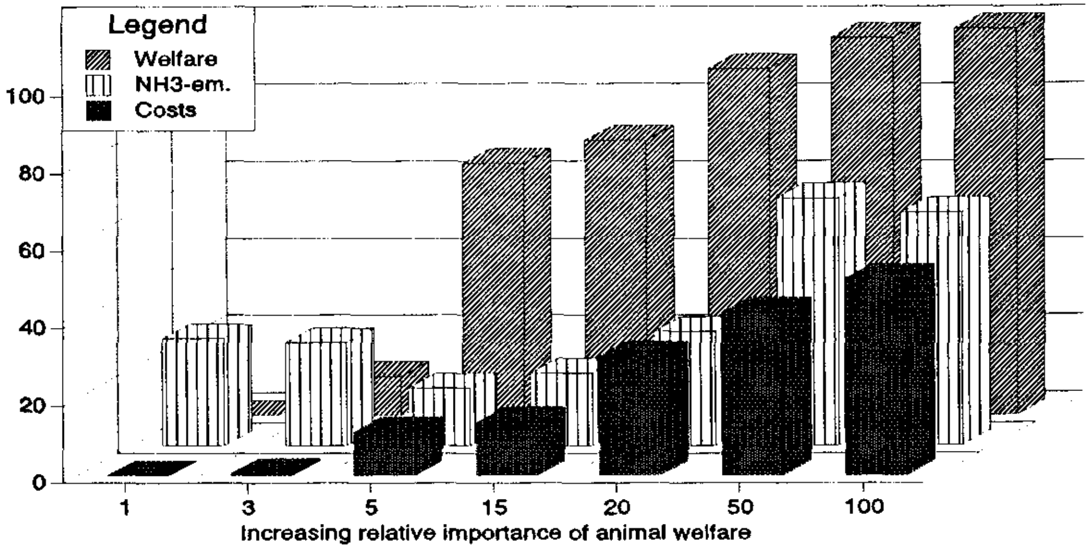

Figure 5. Effects of increasing the importance of an improved animal welfare on additional costs per hog, and the reduction of ammonia emission

chain, incurred in case a maximum level of 100 animal welfare point is desired, account for approximately 22% of the total chain production costs from farrow to slaughtering, in the default situation.

The same trend of progressively increasing costs at increasing constraints, becomes apparent in case higher levels of reduction of ammonia emission were desired. Some attributes, such as the percentage of concrete floor space and the outdoors space, are both related to pig welfare and environmental pollution (ammonia emission). While the first is believed to influence both criteria positively, that is to benefit the welfare of the pig and to reduce the ammonia emission, the second one is believed to have a reverse effect. Allowing pigs to outdoors space is considered beneficial with respect to the welfare of the animal, but harmful to the environment as it increases ammonia emission (Verdoes, 1990). In case an increase in animal welfare is desired simultaneously with a decrease in ammonia emission, this attribute will cause conflicts. As an example, goal programming (Romero and Rehman, 1989) is used to evaluate the effects of increasing the importance of animal welfare in relation to environmental pollution, on both criteria and costs incurred per hog at the fattening stage.

At first the ammonia emission is reduced simultaneously with an increase in animal welfare (*Figure 5*). However, when a conflicting attribute is added to the concept to improve animal welfare, the ammonia emission increases again, as shown by a lower percentage of reduction of ammonia emission in Figure 5.

Concluding remarks

By means of the chain simulation model, it was shown that cost and benefits of differentiated pork chain products, can be quantified per stage as well as for the chain as a whole. Using a chain model instead of separate stage simulation models, offers the advantage of taking into account interstage relations, which were quantified for both economic effects and animal welfare aspects. Various criteria, such as economic, animal welfare and environmental criteria, concerning the pork production-marketing chain, were taken into account. Animal welfare coefficients, were quantified using the conjoint analysis in a questionnaire sent both to pig welfare experts and consumer related groups, such as advocacy groups and retailers. In using this method both main effects of the welfare attributes considered, and interaction effects, could be quantified. Moreover, the number of profiles, i.e. combinations of attributes, a respondent had to evaluate, could be reduced considerably, by using this method. At analyzing the questionnaires, major differences were found with respect to the valuation of animal welfare attributes by the various respondents. Moreover, is was found that, although the coefficients of one respondent proved to be significantly predictively valid for all cases, most other respondents yielded less consistent result. In the data, no statistical significant difference could be found between the group of experts versus the group of consumer-related respondents. By means of an optimisation model, based on linear programming, the effects of increasing levels of desired pig welfare on the production costs of a pig in the chain, could be quantified. The pig welfare coefficients of both an expert and a consumer representative, used in the optimisation model, resulted in relatively small differences. However, as a high variation was found in opinions regarding how to improve pig welfare along the chain, this does not have to hold for the coefficients of other respondents. The optimisation model was also used to take environmental effects into account, besides animal welfare and costs. Both increasing demands on animal welfare and environmental pollution, proved to result in progressively increasing costs along the pork production-marketing chain to meet these demands. Besides additional costs incurred by fulfilling demands on animal welfare and environmental issues, it may be possible that - a certain segment of - consumers are willing to pay a surplus value for these products. Using the pork chain simulation and optimisation models, it can be calculated how big the extra price should be to make a differentiated chain system profitable, or at least to break-even. However, additionally to marketing research to estimate how many consumers are willing to pay which amount of money, research is needed on ways to redistribute this surplus value back along the stages of the chain. Moreover, several production and market risks are involved in producing this kind of differentiated products. For example, it may happen that due to health circumstances, hogs may no longer meet the specific standards of a differentiated chain concept, and devalued to a lower concept. Although additional costs already have been incurred, the surplus value is missed then. Within the total research project, of which the study described in this paper is a part, these subjects are taken into consideration as well.

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Appendix I. Major technical and economic default values of the pork simulation model

Variable	Default
Farrowing	
Duration of production cycle of a sow (days)	153
Max. no. of breedings per production cycle	3
Age at which feeder pigs are sold (days)	70
Litter size (piglets born alive)	10.8
Piglet mortality rate (%)	14.5
Culling rate of young and mature gilts resp. (%)	25/10
Price replacement gilts	
young (age 10 weeks) (Dfl./head)	220
mature (age 6.5 months) (Dfl./head)	520
Price feed (Dfl./100 kg)	
piglets	66.40
non-lactating sows	42.10
gilts, lactating sows and boars	46.35
Feeder pig price (Dfl./head)	107.58
Fattening	
Average growth rate of hogs (grams/day)	719
Standard deviation growth rate (grams/day)	72
Mortality rate (%)	2.1
Number of hog deliveries per production cycle	2
Distribution of hogs over 1st and 2nd delivery (%)	20/80
Number of pens per compartment of the barn	8
Price of feed first part fattening period (Dfl./100 kg)	52.3
Price of finishing feed (Dfl./100 kg)	43.6
Price of finishing feed (Dfl./100 kg)	45.5
Meat price (Dfl./kg slaughter weight)	3.41
Hog transportation	
Loading density transportation (kg live weight/m^2)	300
Occupation rate transportation truck (%)	90
Distance covered per drive (km)	175
Slaughtering	
Hogs condemned at life visual inspection (%)	1.6
Boars supplied (%)	4.8
Slaughter efficiency (%)	77
Hogs without slaughter deviations (%)	79
Relative distrubution slaughter deviations (%)	
Pleurisy	48
Abcesses in Lungs & Pneumonia	32
Lungs impossible to mark	9
partially Affected Liver	1
Condemned Liver	6
Inflammation of the Leg	3
Skin Lesions	1
Ratio Sold as carcass : Sold in parts	30:70
Slaughtering labour (Dfl./hour)	35