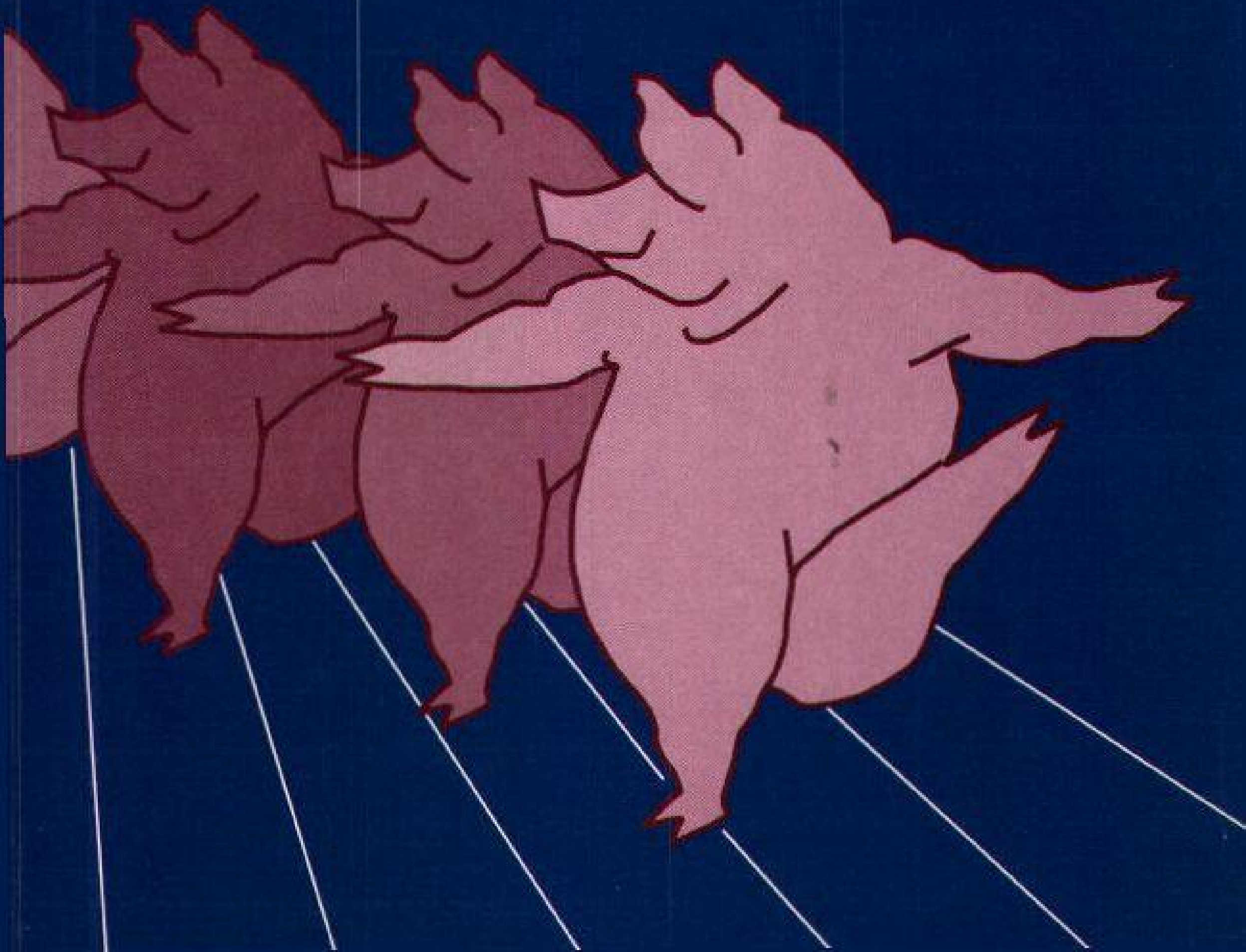
Economic modelling of pork production-marketing chains

M. den Ouden



Stellingen

1. Optimalisatie per schakel kan leiden tot suboptimalisatie van de keten als geheel.
Dit proefschrift

2. Onjuiste verrekenprijzen spelen een belangrijke rol in het veroorzaken van ketensuboptimalisatie.
Dit proefschrift

3. Naarmate hogere eisen worden gesteld aan dierlijk welzijn in de varkensketen stijgen de daarmee gepaard gaande kosten progressief.
Dit proefschrift

4. Maatregelen ter verbetering van dierlijk welzijn kunnen conflicteren met milieudoelstellingen. Als gevolg daarvan verandert bij gelijktijdige, in plaats van afzonderlijke, economische beschouwing, de volgorde waarmee deze maatregelen zouden moeten worden geïmplementeerd.
Dit proefschrift

5. Het ketenonderzoek in de landbouw is nog te kwalitatief van aard. Voor een succesvolle uitbouw van de ketengedachte zijn meer aandacht en middelen gewenst voor een kwantitatieve economische benadering.
Dit proefschrift

6. Gericht marktonderzoek en een bewuste marktbenadering zijn cruciaal voor het behalen van economische meerwaarde van nieuwe gedifferentieerde ketenprodukten.

7. Te veel wetenschappelijk onderzoek eindigt als weten op een schap. Integratie van onderzoek en praktijk via externe financiering en commerciële vermarkting zou in dit verband een goede zaak zijn.

8. Beslissingsproblemen bestaan alleen wanneer meerdere (conflicterende) criteria de keuze van de oplossing bepalen. In andere gevallen is er slechts sprake van zoeken en meten.
Romero, C. and Rehman, T. (1989). Multiple criteria analysis for agricultural decisions. Elsevier, Amsterdam.

9. Het zou de vooruitgang in de wetenschap ten goede komen als hoogleraren, zoals hun promovendi, niet zonder meer voor het leven worden benoemd maar periodiek getoetst worden.

10. Volgens Sonnert and Holton (1996) publiceren vrouwelijke wetenschappers weliswaar minder vaak dan hun mannelijke collega's, maar is datgene wat zij publiceren doorgaans van een hogere kwaliteit. Helaas wordt dit laatste ontkracht door het feit dat het achterliggende onderzoek door mannelijke wetenschappers is uitgevoerd.
Sonnert, G. and Holton, G. (1996). Career patterns of women and men in the sciences. American Scientist, January-February, 63-71.

11. Vanwege het feit dat het duurste kattevoer duurder is dan varkenshaas, kan men zich afvragen of sommige beesten een mensachtig bestaan leiden of andersom.

12. Hoewel de Salmonella problematiek zeker niet onderschat mag worden, leven er vooralsnog meer mensen van dan er aan sterven.

M. den Ouden
Economic modelling of pork production-marketing chains
Wageningen, 4 oktober 1996

Economic modelling of pork production-marketing chains

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Economic modelling of pork production-marketing chains

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus,
dr. C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 4 oktober 1996
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Abstract

Economic modelling of pork production-marketing chains
Economische modellering van produktie-marketing ketens voor varkensvlees
den Ouden, M., 1996.

The research described in this thesis was focused on the development of economic simulation and optimization computer models to support decision making with respect to pork production-marketing chains. The models include three production stages: pig farrowing, pig fattening and pig slaughtering including cutting of carcasses. Transportation of live pigs between these stages was also considered. The pork chain simulation model was developed and described to simulate technical and economic performance of both individual stages and pork chains as a whole. Special attention was focused on the quantification of the way in which stages can influence each other's performance and profitability. The simulation model was used to analyse the distribution of costs and benefits along the stages of the pork chain using various transfer pricing systems. Besides the chain producing standard pork, three differentiated pork chain concepts were evaluated. The simulation model was also used to quantify the impact of pig welfare demands on the economics of the pork chain. Pig welfare perceptions were assessed from animal welfare experts, retailers and other consumer-related respondents using a questionnaire based on conjoint analysis. The estimated pig welfare perceptions and corresponding economics were used as input parameters for static and dynamic linear programming models to analyse the development of least-cost chain concepts satisfying increasing demands on pig welfare. Additionally, the optimization models were extended using multi-criteria-decision-making techniques to include the effects on nitrogen and phosphorus emissions and energy consumption in pig farming as well.

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Acknowledgements

Writing a PhD-thesis is somewhat like a chain process. It also involves several stages of activities. Starting from conception of the idea it goes via multiplying, growing, transmitting and processing to final consumption. Moreover, it asks for coordination and is, as a whole, embedded in a network of other related 'suppliers' or 'buyers'.

In the breeding stage various people of both Nutreco and the Wageningen Agricultural University initiated the birth of this project. I am very grateful to the general management of Nutreco and the Hendrix companies for suggesting the subject, offering the (financial) possibilities and allowing me a unique, one-in-a-million, propitious opportunity to continue my scientific training in a business environment. For this stage I would like to thank Jos Raaymakers, Henk Bakker and Siem Korver of Nutreco and Aalt Dijkhuizen of the Wageningen Agricultural University in particular. Aalt's enthusiastic, inspiring and professional guidance during my Master's thesis triggered enough 'reasonable doubts' to consider this PhD-study.

Coordination of the PhD-project was provided by Prof. Aalt Dijkhuizen and Dr. Ruud Huirne on a structural basis and less frequently by the scientific steering committee. Dear Aalt and Ruud, your supervision has been most inspiring, motivating and scientifically stimulating. You both have been a father, a friend and a teacher to me. One of the biggest compliments I have ever received from one of my own students was the remark that 'I just sounded like Aalt'. I know that I am sometimes too much of a perfectionist and a bit stubborn. It is somewhat like Dutch meat consumers: they agree on improving animal welfare when asked, but afterwards do not buy it. However, you two always knew how to pull me to a higher and more direct quality. My sincere thanks for this.

After conception of the project, ideas often multiplied during meetings with the scientific steering committee. I would like to express special gratitude to Prof. Jan Renkema, Prof. Paul van Beek and Dr. Peter Zuurbier of the Wageningen Agricultural University and Ir. Bert van Gils, Dr. Siem Korver and Ir. Albert Swinkels of Nutreco for their specific and significant contribution to this project.

In the growing and transmitting stages, ideas were worked out and transferred into results. I owe many people my thanks for the useful suggestions and comments on my work. The colleagues of the Department of Farm Management created an enjoyable and stimulating working environment. They also facilitated the growing stage in a direct sense by all the cake we ate. Special thanks to Alien Jalvingh, Jos Verstegen, Eric Houben and Toin Buytels for helping with Pascal, Word Perfect and statistics and being good (room)mates. All the colleagues at Nutreco: I very much appreciated your interest, practical viewpoints and support. Rob Krabbenborg, Henk Schreurs, Peter van Asten, Adam Sneep, Willemien Rook, Wim Brunnekreef, Lammert Veenhuizen, Linda Rietveld, Henk Vos, Hilbrand Meesters, Wim van de Kamp, Marie Vermeulen and all others are thanked for useful comments and/or (AUSPIG-)calculations. In the transportation area, people of Select Porc provided valuable insights, and, figuratively speaking, the car pool is thanked for physical transportation of myself and any mail. Specific gratitude goes to Janneke Nijsing for the effort she put into the animal welfare questionnaire and preparation of the linear programming model. Special thanks are also due to the respondents who were willing to complete the animal welfare questionnaire and to Prof. Carlos Romero of the Polytechnical University of Madrid and Prof. Michael Boehlje of Purdue University (USA) for their comments on the chapter on multi-criteria-decision-making.

Almost at the end, all materials have to be processed properly to fit into this booklet. I would like to thank Diny Dijkhuizen for screening the English text and Ernst van Cleef for designing the cover. Finally, the stage of consumption. At last there is a concrete end-product: the thesis. Family and friends may enjoy the completion of this research because they will get the deserved time and attention in the future (hopefully). Last but certainly not least, therefore, I would like to show my appreciation to all friends and relations in my personal network. Whether they supplied fruits and vegetables (Piet Neefjes), housekeeping services ('Jet' van den Elzen), printing and faxing facilities (Haitze Meurs) or 'just' good friendship, understanding and interest, they all contributed to the supportive conditions during this research. This especially applies to my parents who stimulated me to reach for the best and do not settle for less, and my partner Ivo. Ivo, you always made me see things in perspective, shared the victories of the 'ups' and the strengthening experiences of the 'downs'. Thanks for all your love, support and understanding and for making me laugh.

Marjan,
Wageningen, August 1996.

Contents

Chapter 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Due to specialization and concentration, the production and marketing of pigmeat are distributed over several, more or less independent farm and agribusiness firms, that is in Western regions of the world. Together the firms involved in subsequent stages of transformation of raw materials into final pork products are called production-marketing chains. Because they are linked vertically the various stages may influence each other's technical and economic performance, and conflicting goals and incentives between chain participants may occur (Marion, 1976; Miller 1994). As a result, optimization from the perspective of each individual stage may suboptimize the economic result of the chain as a whole (Gilbert and Strebel, 1988). To avoid this suboptimization understanding and quantification of vertical linkages, and vertical coordination are needed. This becomes even more important, as current consumer attention for the quality of the final food product and the way of production increases (Barkema, 1993; Miller, 1994), creating opportunities for product differentiation. Commodity industry is more and more being replaced by one with differentiated products (Boehlje, 1996). Especially in the case of fresh food products and consumer demands concerning issues, such as pig welfare and environmental pollution, this implies the transmission of those (changed) consumer preferences to preceding stages which supply the raw or intermediate materials (Boehlje, 1996). Putting special demands on stages will change their performance and profitability and potentially that of subsequent stages via interstage relations. Elaboration on the economics of product differentiation including the (changed) distribution of costs and benefits among chain participants, provides quantitative tools to control chain activities for example, through a differentiated transfer pricing system. Because prices influence incentives affecting economic decisions, transfer prices can be used to serve as effective signals to transmit buyer demands through all stages of the chain and simultaneously redistribute a potential premium consumer price back to the stages involved.

Until recently many technical and economic research and system simulation models in pork production have focused on a single farm or agribusiness firm (Jalvingh, 1992). The research project on integrated quality control in slaughter pigs (Elbers, 1991) was one of the first in - Dutch - pig production that concerned (technical) relations between pig fattening and slaughtering operations. The pig breeding area has also been more concerned with interstage relationships, and Hovenier (1993), for instance, considered breeding effects on pigmeat quality. Economic evaluations are still limited, however.

The objective of this thesis was to develop an economic pork chain simulation model in which technical and economic performances could be simulated for both individual stages and the chain as a whole. The model should allow for the quantification of the distribution of costs and benefits among the chain participants in general and of interstage relations and the impact of product differentiation in particular. Economics of both current and potential future pork chain concepts should be evaluated, including their implications for transfer pricing systems. In order to optimize pork chain concepts of various and sometimes conflicting criteria such as economics, environmental pollution and pig welfare, optimization models had to be developed using linear programming and multi-criteria-decision-making techniques.

1.2 OUTLINE OF THE STUDY

In Chapter 2 a literature review on vertical coordination in production-marketing chains is given with special reference to agriculture and product differentiation in pork. Although in the literature the potential advantages of vertical cooperation and the importance of integral analyses are recognized, quantitative chain analyses seem to be lacking. Therefore, it was decided to develop an economic pork chain simulation model to allow for the quantification of pig chain issues in general and the way in which stages can influence each other's performance and profitability in particular (Chapter 3). By analysing the effects of various stage- and chain-related variables on the distribution of costs and benefits, it was aimed to analyse whether individual stages, by optimizing their individual goals, could suboptimize the chain result as a whole. In Chapter 4 the analysis is extended to include the effects of various transfer pricing systems, as these seem to be potential sources of suboptimization. Application is directed towards three differentiated pork chain concepts based on real-life examples in the Dutch market. Besides current (and past) pork chain concepts, it would also be interesting to explore the effects on economics and chain structure by anticipating potential future changes in customer demands and their implications for pork product differentiation. Effects of changing demands regarding pig welfare perceptions are examined in Chapters 5 and 6. Besides the underlying simulation model, methods used include a pig welfare questionnaire based on conjoint analysis (Chapter 5) and dynamic linear programming (Chapter 6). Customer demands may simultaneously concern varying product attributes, ranging from food safety considerations, nutritional values, animal welfare and environmental issues. In Chapter 7, therefore, the economic optimization model focusing on animal welfare issues is transformed into a compromise programming model to also include the sometimes conflicting effects on nitrogen and phosphorus emissions and energy consumption in pig farming.

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Chapter 2

VERTICAL COOPERATION IN AGRICULTURAL PRODUCTION-MARKETING CHAINS, WITH SPECIAL REFERENCE TO PRODUCT DIFFERENTIATION IN PORK[1]

ABSTRACT

Optimization of individual stages within a Production-Marketing Chain (PMCh) may cause a suboptimal result of the PMCh as a whole. Market imperfections and conflicting interest may be the causal factors. Although vertical integration is often mentioned as the conventional solution, certain disadvantages and the large scale differences in agricultural PMChs make vertical cooperation a more appropriate alternative. Moreover, specific characteristics of agricultural food chains and changing market circumstances, including increased interest in the quality of products and production processes, justify renewed attention to vertical cooperation and product differentiation in agriculture. Current developments in the Dutch pork PMCh and implications on future research are described.

2.1 INTRODUCTION

During the past decades the trend in Western agriculture has been toward greater specialization in fewer commodities and in fewer stages in the production, distribution, and marketing of each commodity (Mighell and Jones, 1963). As a result, production and marketing of many agricultural food products are distributed over several, more or less independent, farms and agribusiness firms, each performing one stage of the transformation of raw materials into final consumer products. Theoretically the successive steps or activities involved can be subdivided indefinitely (Ikerd and Higgins, 1973; Pennings et al., 1984; Porter, 1985). However, in defining the boundaries between stages, most authors emphasize technological, functional, geographical, and/or economic separability (Mighell and Jones, 1963; Ikerd and Higgins, 1973; Pennings et al., 1984; Porter, 1985; Perry, 1989; Romme, 1990). Because this study was especially concerned with the interstage coordination of activities performed within separate organizations, stages are described in economic terms. An 'economic' stage is defined as the combination of activities performed between two adjacent marketing levels, that is a saleable product or

[1] paper by Den Ouden, M., Dijkhuizen, A.A., Huirne, R.B.M. and Zuurbier, P.J.P. published in *Agribusiness: an International Journal 12 (3) (1996): 277-290.*

service exists at the separation between stages (Mighell and Jones, 1963; Ikerd and Higgins, 1973). This means that a 'stage' is defined within the boundaries of a firm. Together these stages form a so-called Production-Marketing Chain (PMCh) or value system (Porter, 1985).

With the establishment of PMChs, the distance between consumers and primary producers increased (Dalton, 1982), possibly contributing to the development of at least partially conflicting goals and incentives that may exist between chain participants (Marion, 1976; Porter, 1980). As early as 1973, Purcell (1973) and Marion and Arthur (1973) reported conflicts between stages in a beef and a broiler PMCh, respectively. Examples included conflicts and inconsistencies in the overall goal of operation, the valuation of the animals, the desired level of information exchanged (Purcell, 1973), the distribution of returns, control over decisions, and the sharing of risks (Marion and Arthur, 1973). More recently, Miller (1994) described differences in quality concerns among participants of the US pork chain. Because of these conflicting interests and related imperfections in communication or coordination, the participants of the chain may, by optimizing from their individual perspectives, **suboptimize** the economic result of the chain as a whole (Gilbert and Strebel, 1988). Suboptimization refers to inefficiency and/or inefficacy. That is, the goods in the chain are produced, distributed, or marketed neither efficiently nor effectively, in the sense that they fail to match the preferences of the consumers (Marion, 1976). Markets are supposed to harmonize supply and demand optimally both in quantity and quality by means of the price system (Marion, 1976). However, the theoretical assumptions underlying those perfect markets, including perfect information, perfect competition, stable environments, and rational behavior, often do not hold in practice (Marion, 1976; Brand et al., 1988). With regard to information, for instance, 'the larger the number of stages and the more geographically dispersed, the more difficult the communication of accurate information' through the chain will be (Marion, 1976; Bocksteal, 1987). Furthermore, complexity, uncertainty, and small numbers of buyers and sellers (imperfect competition) are no exceptions in the real world and give rise to bilateral interdependency, which increases the likelihood of opportunistic behavior (Pennings et al., 1984; Perry, 1989; Williamson, 1989).

According to Hanf and Wright (1992), 'Currently, the growing awareness of the importance of product quality by agribusiness managers contrasted to the increasing dissatisfaction with product quality amongst consumers may be interpreted as an example of a failure of the existing market system.' Vertical integration is often mentioned as the conventional solution to dissolve the destructive results of market failures (Johnston and Lawrence, 1988). After presenting the pros and cons of complete vertical integration, this article focuses on the importance of incomplete vertical integration, or vertical cooperation, as a more applicable solution in current agricultural PMChs. The concept of a 'chain-wise' production in a PMCh and of vertical cooperation, are not new at all.

However, because consumers and society in many countries show increasing interest in methods of production and product quality (Sloan et al., 1984; Burbee and Kramer, 1985; Van Gaasbeek, 1990; Barkema, 1993) concerning issues such as animal welfare (Guither and Curtis, 1983), environmental pollution, and food safety (Burbee and Kramer, 1985; Barkema, 1993), even more demands are made on the level and smoothness of vertical coordination and communication. Vertical cooperation concepts receive renewed attention in this respect. Therefore, the use of vertical cooperation is discussed with special reference to agriculture and product differentiation. Developments in Dutch pork PMChs are described. Finally, attention is paid to future research needed to support agricultural PMCh decision making.

2.2 VERTICAL INTEGRATION

Vertical integration can be defined as the combination of two or more stages of a PMCh under single ownership (Mighell and Jones, 1963; Marion, 1976; Porter, 1980; Buzzell, 1983; Van Heck and Zuurbier, 1989; Williamson, 1989). Motives in favor of and against vertical integration are discussed in the next sections under two basic headings: achievement of economies and market power (Brand et al., 1988; Mulligan, 1989) (Table 2.1).

2.2.1 Motives in favor of Vertical Integration

Ever since Coase (1937) wrote 'The Nature of the Firm' in 1937, the reduction of transaction costs has formed an important argument in favor of vertical integration (Table 2.1). Transaction costs are the costs associated with the process of exchange itself (Bradach and Eccles, 1989; Perry, 1989). Transactions are characterized in terms of three dimensions that dictate whether market exchange or internal governance of transactions is most efficient: asset specificity, uncertainty, and frequency (Perry, 1989; Williamson, 1975, 1989). When transactions recur frequently and require high transaction-specific investments, opportunistic behavior is likely to occur, causing transaction costs to rise and markets to be replaced by more efficient internal organization of the exchange through vertical integration (Perry, 1989; Williamson, 1975, 1989).

In the same way that vertical integration should reduce transaction costs, being the resources consumed in the exchange of intermediate technological inputs, vertical integration may also reduce the amount of technological inputs itself (Clarkson and Miller, 1982; Perry, 1989). The argument of economies of internal control and coordination is often associated with the characteristic of vertical integration to assure supply in terms of reducing its uncertainty (Table 2.1). In this way the need for inventory or other slack built into the business may decline (Porter, 1980). Reduction of uncertainty is especially important to capital intensive stages where shortages of material lead to low usage of expensive facilities (Buzzell, 1983).

Increased control over adjacent stages may also enhance the ability of a firm to innovate or differentiate its product (Porter, 1980; Buzzell, 1983; Perry, 1989). Whereas forward integration gives the firm better or more timely access to market information, allowing a more rapid or specified adjustment of product characteristics, backward integration may allow the firm to obtain specialized inputs through which it may improve or at least distinguish its final product (Porter, 1980).

Table 2.1 Summary of potential advantages and disadvantages of Vertical Integration

Advantages	Disadvantages
Economies	
- reduction of transaction costs	- high capital investment requirements - unbalanced throughput because of differences in efficient scale:
- technological economies - enhanced ability to differentiate	- diseconomies of scale - reluctant independent suppliers/buyers
- economies of internal control and coordination	- dulled or attenuated incentives and bureaucratic distortions - differing managerial requirements
- economies of information - economies of stable relationships	- possibly missing advantageous external opportunities - reduced flexibility to change partners
Market Power	
- elevate entry barriers and mobility barriers - raise rival costs by foreclosure - practise price discrimination - offset bargaining power and input price distortions - defend against foreclosure	- higher overall exit barriers - foreclosure of access to supplier or buyer research and/or know-how

Although it is not clear that vertical integration should be characterized as necessary to reveal valuable information, once accomplished it should at least facilitate information exchange for vertical integration increases the likelihood and duration of exchange between stages (Perry, 1989). Moreover, vertical integration may cause the firm to require less information, thereby reducing costs, for example for collecting and processing information about the market (Porter, 1980). Of course, those potential advantages must be balanced against the costs of possibly missing advantageous external opportunities (Perry, 1989) (Table 2.1: disadvantages of vertical integration).

As well as facilitating information transfer, the assurance of a stable relationship may encourage the development of more efficient, specialized procedures for dealing with each other (Table 2.1). Without a stable relationship, both buyer and seller would face the competitive risk of being dropped or squeezed by the other party. In fact, vertical integration may be both the cause (Porter, 1980) and result of the establishment of transaction-specific assets (Williamson, 1985, 1989).

The more significant the net benefits arising from those economies of vertical integration, the greater the competitive advantage of the integrated firm over unintegrated firms and thus the greater the stimulus to other firms to integrate as well (Porter, 1980). In the case of significant economies of scale or capital requirements to integrate, vertical integration creates entry and mobility barriers (Clarkson and Miller, 1982; Brand et al., 1988). Compared to a nonintegrated entry, an integrated entry will also require managerial expertise at more than one stage (Buzzell, 1983; Mulligan, 1989). As well as discouraging potential new entrants, a dominant firm may use vertical integration to impair its competitors by raising their costs. Foreclosure of the market may subject competitors of an integrated firm to higher prices set by fewer remaining independent suppliers, to higher transaction costs from having to negotiate on contracts with remaining suppliers or buyers (Perry, 1989), or to having to deal with remaining suppliers or buyers that are inferior to those secured by integrated firms (Porter, 1980). Moreover, an imperfect competitive firm, that is, a monopolist, may use vertical integration to practice price or quantity discrimination toward adjacent competitive stages, resulting in price or supply squeezes. On the other hand, the fear of foreclosure and countervailing of bargaining power may be primary incentives for vertical integration (Brand et al., 1988; Perry, 1989; Romme, 1990) (Table 2.1).

2.2.2 Motives against vertical integration

According to Buzzell (1983) 'a problem inherent in combining various stages of production or distribution is the varying scale of operation that each stage may require for efficient functioning'. Here the firm contemplating vertical integration faces a dilemma. Either it must accept a cost disadvantage in operating on inefficient scales at one or more stages, or it has to sell outputs or purchase inputs on the open market (Porter, 1980; Buzzell, 1983). Selling or buying excess output or demand on the market may be difficult because the vertical relationship implies that the integrated firm may have to sell to or buy from its competitors. The latter may be reluctant to deal with the firm or even take retaliatory action (Romme, 1990). Moreover, the integrated firm may foreclose itself from access to independent supplier or buyer research or know-how (Porter, 1980).

Vertical integration consumes capital resources (Table 2.1). To make vertical integration profitable high investments need to be offset by substantial cost savings, or returns greater than or at least equal to the firm's opportunity cost of capital (Buzzell, 1983). High investments may raise exit barriers and reduce flexibility (Porter, 1980; Johnston and Lawrence, 1988). Changes in technology, product design, and market developments may cause the products or technologies of the integrated stage(s) to become more costly, inferior in quality, or inappropriate compared with those of independent suppliers or buyers. The integrated firm is then confronted with higher switching costs than would have been the case when it had contracted with independent partners (Porter, 1980).

Another risk of vertical integration is embodied in managing the various stages that may require distinctly different managerial approaches, for example, manufacturing compared with marketing (Buzzell, 1983; Johnston and Lawrence, 1988; Mulligan, 1989). Moreover, tightly linked, captive, and assured relations between the stages within an integrated firm may cause dulled incentives (Porter, 1980). Compared with internal organization, in general, markets promote high-powered incentives and restrain bureaucratic distortions more effectively (Williamson, 1989).

2.3 VERTICAL COOPERATION

2.3.1 Motives and definition

Potential benefits and potential costs and risks of vertical integration as compared to market exchange may be great. However, the choice, market exchange or vertical integration, is not a black or white one (Van Heck and Zuurbier, 1989). Several authors (Mighell and Jones, 1963; Klein et al., 1978; Porter, 1980; Buzzell, 1983; Riordan, 1984; Johnston and Lawrence, 1988; Bradach and Eccles, 1989; Perry, 1989; Powell, 1990; Romme, 1990) recognized the possibilities of gaining many of the advantages of vertical integration without incurring all of its costs and risks through the use of some kind of incomplete vertical integration. Incomplete vertical integration or **vertical cooperation** refers to vertical relationships between two or more adjacent stages without full ownership or control, (Kirsch, 1976; Porter, 1980) in which the partners fundamentally maintain their independence (Mighell and Jones, 1963; Johnston and Lawrence, 1988) but, for example, share information or coordinate pricing. In other words, control is transferred of **some, but not all**, aspects of production, distribution, or marketing (Perry, 1989). Vertical cooperation is a way of 'broadening scope without broadening the firm' (Porter, 1985). On the continuum from market exchange to vertical integration, vertical cooperation mechanisms can take many different forms, for instance, subcontracting agreements, franchising, or joint ventures (Powell, 1990). These modes differ in duration, type, and degree of control or ownership (Mighell and Jones, 1963; Ikerd and Higgins, 1973).

Figure 2.1 shows the difference in distribution of control between market exchange, vertical cooperation, and vertical integration. Each square represents a stage of a hypothetical PMCh. Continuous lines are used to symbolize the distribution of control over activities performed along the chain. Dotted lines indicate some kind of 'external' control. Theoretically, in the case of market exchange, control is fully located at the separate stages (squares have continuous lines), and coordinated solely by market prices (dotted lines). With full vertical integration, control is completely shared or transferred to central management (continuous surrounding and linkage lines), leaving the different stages without separate control (dotted lines). Vertical cooperation mixes those two extremes.

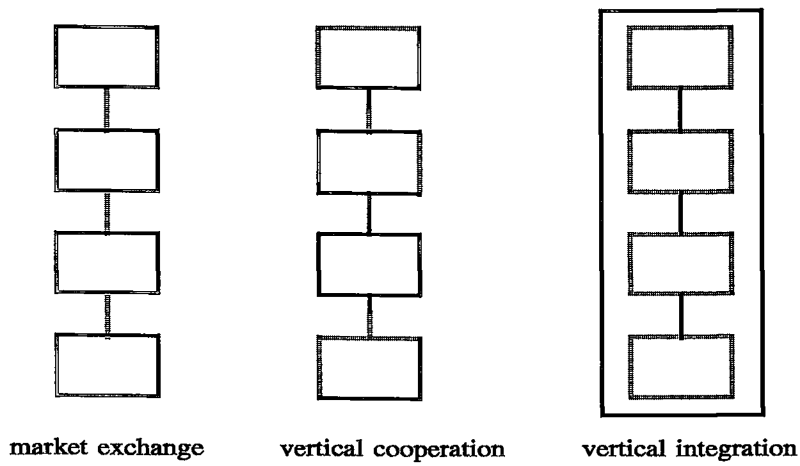

Figure 2.1 Comparison of three types of vertical coordination in a PMCh: market exchange, vertical cooperation and vertical integration
(———— 'internally' controlled; .... 'externally' controlled)

2.3.2 Importance of vertical cooperation in agricultural food chains

With respect to PMChs producing agricultural food products, the big scale differences between the various stages are often mentioned as the main reason for making complete vertical integration in one organizational unit less common than other forms of vertical coordination (Mighell and Jones, 1963; Kilmer, 1986; Hanf and Wright, 1992). The scale differences in the Dutch PMCh producing pigmeat are presented in Table 2.2 (Klein Kranenberg and De Vlieger, 1988; Van Driel, 1988; Borgstein, 1994; De Vlieger et al., 1995). The data are based on studies to the distribution structure of pigs and pigmeat in

1986 (Klein Kranenberg and De Vlieger, 1988; Van Driel, 1988) and 1991 to 1992 (Borgstein, 1994; De Vlieger et al., 1995) in the Netherlands. Compared to 1986, in 1991 the number of pig farms decreased by approximately 24%. Pig production is still dominated by family operated firms. From 1986 to 1991, the average scale increased from 1230 feeder pigs and 810 fattened pigs sold per year to 1746 feeder pigs and 910 fattened pigs sold, respectively (Table 2.2). Since 1986, the number of organizations involved in slaughtering, trading and processing pigmeat increased. This could be partly explained by the establishment of small specialized slaughtering firms, specialization benefits of international trade, and a growing demand of further processed meat cuts, respectively (De Vlieger et al., 1995). At the same time, however, these stages became more concentrated. Whereas in 1986 50% of the pig slaughtering organizations together traded 89% of all pigmeat, this market share was held by only 8% of the pig slaughtering firms in 1992 (Table 2.2). Moreover, the number of pig slaughterhouses slaughtering at least 25,000 pigs annually, decreased from 58 in 1986 to 37 in 1992 (Anonymous, 1994a). In contrast to 1986, the 1991 to 1992 studies did not include retail and large scale consumption but figures and trends were deduced from other sources. There were no comparable figures available of large scale consumption. With respect to retail, the general trend of increasing scales and market shares of supermarket stores proceeded at the cost of butchers (De Vlieger et al., 1995).

If high concentration is considered necessary for market power to exist, market power-based incentives will be less important for the farm stages characterized by low seller/buyer concentration (Table 2.2). Traditionally, farmer-owned cooperatives were formed to join forces and offset bargaining power of the more concentrated supplying or marketing stages. Cooperatives are familiar, widespread, and particular forms of vertical integration in agriculture (King, 1992). Being so closely linked to farmers, cooperative processing firms may face an advantage in transferring changed customer preferences back to farmers (Anonymous, 1994b). However, one of the two Dutch cooperatives slaughtering and processing pigs is characterized by the fact that the farmer members may not be under contractual obligation to supply all their pigs to the cooperative. Moreover, reconciliation of corporate and member objectives and capital sourcing and retention needed to invest in product development, may represent specific additional problems (Stewart, 1993).

Table 2.2 Indication of scale differences between the various stages of the pork PMCh in the Netherlands (Klein Kranenberg and De Vlieger, 1988; Van Driel, 1988; Borgstein, 1994; De Vlieger et al., 1995).

Stage	Number of firms	Average Scale of operation/ year[1]	Market Share[2] Firms	Share
1986				
Breeding	18200	1230	9%	34%
Fattening	25900	810	3%	28%
Slaughtering	113[3]	13,100 *10^3kg	50%	89%
Trade	554	785 *10^3kg	N.A.	N.A.
Processing[4]	104	1,800 *10^3kg	18%	84%
Retail	8908	38 *10^3kg	0.1%	27%
Large Scale Consumption	14564	12 *10^3kg	N.A.	N.A.
Consumers	14,5 million	43 kg/head	-	-
1991/1992				
Breeding	12800	1745	16%	45%
Fattening	23140	910	6%	30%
Slaughtering	248	6,650 * 10^3kg	8%	89%
Trade	863	1,420 * 10^3kg	N.A.	N.A.
Processing[4]	420	635 * 10^3kg	7%	75%
Retail	7456	48 * 10^3kg	0.1%	29%
Large Scale Consumption	N.A.	N.A.	N.A.	N.A.
Consumers	15,1 million	42.4	-	-

N.A.: Not Available

1) Representing the number of animals sold per year (breeding and fattening stages) and kilograms of pigmeat, including bones, disposable fat and other edible carcass products (subsequent downstream stages), respectively.
2) Representing the percentage of largest firms with their combined market share in that stage. With respect to the breeding and fattening stages, the largest firms are characterized by a scale of 200 or more sows and a scale of 1000 or more fattening pigs present in 1991 respectively. The largest slaughtering firms are characterized by trading more than 15,000 * 10^3 kg. of pigmeat in 1986 and at least 10,000 * 10^3 kg. of pigmeat in 1992. The largest processing firms are characterized by trading respectively more than 5,000 * 10^3 kg. of meat products both in 1986 and in 1992. In 1986, the 0.1% largest retailers involve 8 retail chains and more than 1,250 stores. Unfortunately, there were no data available to calculate a concentration ratio indicating the same number of leading firms' combined market share for each stage of the chain.
3) Excluding butchers who slaughter pigs themselves (approximately 1,300 in 1986 and 681 in 1992).
4) Including only the processing firms producing meat products. Excluding processing firms using pigmeat in producing snacks and processing firms melting pig fat (respectively 81 and 20 firms in 1986 and 97 and 3 in 1992).

The cooperative market share of slaughtering pigs (40% in 1992, including 25% supplied directly to cooperative slaughter firms) is relatively low compared with, for example, the supply of dairy milk, and the marketing of fruits and flowers, the cooperative market shares of which were 84%, 85% and 95%, respectively, in 1992 (Anonymous, 1994b).

Slack capacity in expensive and asset-specific pig slaughtering plants as well as the export of live pigs may counterbalance the market power of the concentrated slaughtering stages. Here, vertical cooperation may provide the agribusiness firms with assurance of supply. Based on 1988 to 1989 production figures, slack capacity existed especially at medium-sized (200,000 to 500,000 pig slaughterings per year) and small (<200,000 per year) pig slaughter plants, revealing occupation rates of, on average, 65% and 50% respectively (Anonymous, 1991). In addition, a major part of the products of the Dutch pork PMCh is exported. In 1992/1993, approximately 10% of the feeder pigs, 10% of the fattened pigs, and 56% of the pigmeat were exported (Van Driel, 1988; Anonymous, 1994a). Dutch pig slaughtering and processing organizations face an international sales market that is more perfect than their supply market. As a result of seasonal, cyclic, or other fluctuations in these markets and corresponding market prices, 'market power' of chain participants can fluctuate also. In general, as far as farm and processing stages are concerned, it can be concluded that market power in the Dutch pork PMCh is a relative and dynamic notion, influenced by far more aspects than regional concentration ratios.

Specific market and production characteristics of agricultural food chains that do provide increased attention and additional motives for vertical cooperation, include:

- perishability of many products (Dalton, 1982; Kilmer, 1986);
- variability of quality and quantity of supply of farm-based inputs due to biological variation, seasonality, random factors connected with weather, pests or other biological hazards (Brand et al., 1988);
- difference in lead time between successive stages (Dalton, 1982);
- complementarity of agricultural inputs, meaning that they are available in joint packages only (Dalton, 1982);
- stabilization of consumption of many agricultural products (Anonymous, 1991);
- increased consumer attention concerning both product and method of production (Van Gaasbeek, 1990; Hanf and Wright, 1992; Anonymous, 1992; Barkema, 1993);
- the fact that the internal quality of the raw material is the highest quality attainable for fresh products such as meat (Van Gaasbeek, 1990); and
- the need and availability of capital, especially of the primary farm stages (Ikerd and Higgins, 1973; Kilmer, 1986; Barry et al., 1992).

The perishability of many products puts great demands on duration and conditions of storage, processing, and transportation (Dalton, 1982) in all stages of the PMCh. Due to the limited storage possibilities, the existence of assured markets is very important to suppliers of perishable products (Mighell and Jones, 1963). Moreover, capital intensive processing facilities make an assured and continuous flow of supplied inputs essential to buyers (Buzzell, 1983; Kilmer, 1986; Hanf and Wright, 1992). Differences in lead time between stages imply efforts for matching these to each other. Animals need time to grow, to reach optimal productivity, and cannot be stored alive. Meat production is a process that will inherently lead to a wide range of final products. Complementarity of products makes it impossible to produce in isolation exactly what is required. For example, beef cannot be produced without hides, as hams cannot be produced without pork chops. In general, high quality products cannot be obtained without at least some low quality products (Dalton, 1982).

2.4 VERTICAL COOPERATION IN RELATION TO PRODUCT DIFFERENTIATION

The creation of the European Union (EU) and the evolution of the Common Agricultural Policy was aimed at increasing agricultural productivity, price, and income stabilization and security of food supplies. For Dutch agriculture, as for agriculture in other European regions, the period since World War II has been one of sustained growth and increases in efficiency (Van Dijk and Mackel, 1991). Within an expanding market, farmers found that the most effective way to increase their income was to increase production and production efficiency through specialization and concentration. However, nowadays, markets have become saturated and environmental problems have limited the possibilities for farm expansion. In the Netherlands, the consumption of pigmeat seems to have stabilized at a total of approximately 44 kg/person/year. This concerns the consumption of fresh pork in particular (Anonymous, 1991, 1994a). In the EU, however, the annual pork consumption is expected to rise, mainly caused by increased consumption in the southern (Anonymous, 1991) and eastern European regions. Regarding stabilizing and declining industries, Stigler (1951) argues that vertical integration is the typical development (Brand et al., 1988; Perry, 1989). While a growing industry is characterized by a sellers' market concentrated on cost competition, the maturity stage of a product life cycle marks the shift to a buyers' market with renewed interest in increasing perceived value through product differentiation strategies (Gilbert and Strebel, 1988). Instead of complete vertical integration, vertical cooperation is believed to yield comparable advantages with respect to product differentiation (Mighell and Jones, 1963; Romme, 1990), offering more flexibility in addition. Regarding the expected shortening of product life cycles, the latter aspect can be of great relevance. Moreover, it is also believed that product differentiation itself offers an incentive for firms to cooperate (Bocksteal, 1987; Van Heck and Zuurbier, 1989). Changing consumer demands (Guither and Curtis, 1983; Sloan et al., 1984; Burbee and Kramer, 1985; Anonymous, 1992) concerning animal welfare but also concerning food safety, food quality (Barkema, 1993), and environmental issues (associated with manure production) mainly affect the upstream farm stages, thus requiring the transmission of those (changed) consumer preferences, especially to farm stages (Van Gaasbeek, 1990; Streeter et al., 1991; Barkema, 1993). Moreover, fresh products, such as meat, are characterized by the direct relation between the internal attributes of the final product and those of the primary product (Van Gaasbeek, 1990). For instance, during slaughtering and cutting carcasses into fresh meat products, the quality of the live animal is the highest internal quality attainable for the final fresh product. In fact, after primary production internal quality can only deteriorate. This again implies that (changing) consumer demands have to be converted directly to primary producers. In contrast, in the case of processed food products, harmonizing input characteristics to consumer demands can take place largely in the processing stage through mingling (fresh) products, adding additives such as spices, or by chemical processes (Van Gaasbeek, 1990).

Besides a consumer demand force, Barry et al. (1992) also mention demand forces, driven by efficiency considerations, as well as supply forces for product differentiation at the farm level. Being closer linked to (a smaller number of) suppliers, it is believed that product differentiation could enable food producers to achieve higher efficiencies. Harbers (1991), for example, found that the supply of animal health information and preselection of hogs on the farm could be used to increase postmortem meat inspection efficiency in the slaughterhouse. A supply force such as biotechnology, yielding, for example, cloned animals producing lower fat meat products (Barry et al., 1992), enables a closer match of food products with specific attributes desired by discriminating customers. Advances in information technology may allow consumers to see a wider range of product attributes, and is an effective means of coordinating activities in the PMCh 'from conception to consumption' (Streeter et al., 1991). In this respect the growth in the European electronic data interchange (EDI) market, such as EDI-Pigs and EDI-Flowers (Van Heck, 1993) in the Netherlands, and ongoing developments in (electronic) identification and recording (I&R) systems of animals (Geers, 1994), and certification to ISO-9000 standards or an equivalent standard to assure production quality are relevant developments. Although the international standard ISO-9000 is primarily an intraorganizational affair, the standards are formulated from the perspective of the buyer (De Heer and Ahaus, 1992).

2.4.1 Current developments in the Netherlands

Several factors motivated the Dutch government and food industry to start a national (joint) research project to develop an Integrated Quality Control (IQC) system for slaughter pigs. The IQC research project was carried out from 1986 to 1990. In the project several semigovernmental institutions, three integrated agribusiness organizations, and 470 hog producers participated. The project aimed at developing an integrated quality assurance system for the entire pig chain, by which consumers could be sufficiently guaranteed safety and quality of the end product and producers could use mutually exchanged information to quantitatively and qualitatively optimize pig production and slaughtering including meat inspection. Because information from upstream breeding stages could not reliably be transferred, only the hog fattening and slaughtering stage were included (Elbers, 1991). Some of the results are described briefly below. With respect to the safety of pork, it was concluded that, based on the lower prevalence of residues of antibacterial drugs found in the IQC pigs when compared with the already very low national prevalence in non-IQC pigs, collecting and transferring information on drug use during the finishing period of hogs contributed to higher safety (Den Hartog et al., 1990; Harbers, 1991). Moreover, compared with deliveries of hogs accompanied by (properly completed) information cards, deliveries without or with incorrectly completed information cards proved to have significantly higher levels of carcass lesions (Harbers, 1991). The positive results and insights acquired during the research period led to the introduction of the IQC system, which has been in practice since 1992. In 1993, the feeder pig producing stage was also included in the system. The IQC system requirements, specified by the Product Board for Livestock and Meat (Table 2.3), involve traceability of the pigs at all times and regulations as to hygiene and drug use. Currently, 12 major Dutch pig slaughtering firms with slaughter plants at 20 locations, and approximately 45% of all hogs produced are included in the IQC system (Anonymous, 1994a). Although slaughterhouses are still allowed to slaughter non-IQC hogs as well, farmers have to be exclusive IQC-pig producers. The latter conclude contracts with one or more IQC-certified slaughterhouses and/or pig traders, whereas feeder pigs can only be supplied by IQC-certified breeders. The term of notice of these contracts is 6 months. The entire IQC chain is subjected to inspection by an independent institute.

In the Dutch pig sector there is also an 'Outdoor' pork PMCh system (Anonymous, 1993), as there are several other brand products. The outdoor system pursues an improvement of animal welfare through improvements in housing, treatment, and feeding of the pigs. Also in this concept, farmers have to be exclusive outdoor producers, concluding specific contracts with a 3-months notice. Although this term of notice is shorter than that of the IQC system, the specifications of the outdoor pig production system in the Netherlands (Table 2.3) are far more restrictive, requiring a higher asset specificity of farming and imposing higher exit and entry barriers. As shown in Table 2.3, the specified conditions of each chain system vary considerably. The same holds for the revenues per stage of the PMCh. The producers of feeder pigs and slaughter pigs in the IQC chain are rewarded with a fixed bonus of approximately Dfl. 1.5 and Dfl. 3 per animal, respectively; farmers within the outdoor production system receive a higher, but varying, bonus in addition to the market price. Based on the average 1992 market prices, the bonus in the outdoor system was Dfl. 23 per feeder pig and Dfl. 0.9 per kilogram carcass weight, respectively, representing an increase of 21% and 26%, respectively, compared with the bulk market prices.

Table 2.3 Main characteristics of the Integrated Quality Control (IQC) pork PMCh and the Outdoor pork PMCh, as compared with the bulk pork production system (Anonymous, 1993, 1994a).

Characteristics	IQC	Outdoor
- information	downstream: - logbook including: . origin of pigs . drug use . identification & registration data . feed stuffs used - guarantee certificate: . IQC conditions upstream: - results of meat inspection	downstream: - registration forms: . origin of piglets . identification & registration data - logbook: . drug use
- (veterinary) treatments	- limited drugs are approved for use - GVP[1] veterinarians - drawback period	- no castration, tooth clipping and tail-docking - no weaning until average litter weight of 12 kgs or 7 weeks of age
- feed use	- only GMP[2] suppliers - no feed prior to the transportation of hogs	- no medicines, antibiotics or growth stimulators - max. amount of minerals - roughage
- housing facilities	- no additional conditions (national legislation)	- min. amount of floor space - min. amount outdoor space - no fully-slatted floors - daylight - straw - grouphousing - no tethering of sows
- transportation	- no tranquillizers	- no tranquillizers - no electric prodders - slope loading bridge < 20°

1 GVP denotes 'Good Veterinarian Practices'
2 GMP denotes 'Good Manufacturing Practices'

The increase in pigs slaughtered annually for both the IQC and the outdoor PMCh, is presented in Figure 2.2 (Anonymous, 1993, 1994a). The IQC system aims at becoming the standard for the entire Dutch pig sector and the basis for the development of branded pork products (Anonymous, 1994a). The number of participants in this system is growing rapidly. Moreover, the stages involved in the IQC system are expected to increase as well, because the system is due to be extended to include the processing, wholesaler, and retailer stages of the pork chain (Anonymous, 1994a). Although the absolute number of outdoor pigs annually slaughtered in the Netherlands increased more then 10-fold from

1986, the 1992 market share was still quite low (0.3% (Anonymous, 1993, 1994a) of all hogs slaughtered in the Netherlands). In contrast, in the United Kingdom, outdoor production is estimated at 20% of the total British pig production and is expected to increase to approximately 60% in the near future (Franklin, 1993). Also, in France outdoor breeding is increasing and already accounts for 10% of the national sow herd (Le Denmat at al., 1994). Whereas the focus in the Netherlands is on animal welfare, cost savings seem to be major incentives for outdoor pig production in other EU regions.

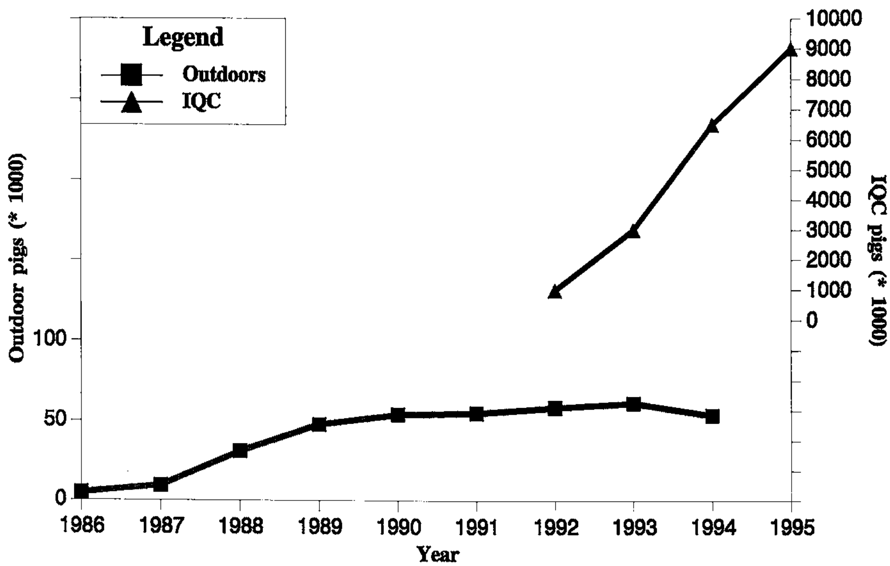

Figure 2.2 Development in the number of pigs annually produced according to the specifications of the Integrated Quality Control (IQC) system and the outdoor system for pig production in the Netherlands (Anonymous, 1993, 1994a).

2.5 CONCLUDING REMARKS

Vertical coordination modes such as vertical integration and vertical cooperation aim at improving efficiency and effectiveness in PMChs. Complete vertical integration may have several disadvantages, such as dulled incentives and reduced flexibility. In addition to the typical big differences in scale between successive farm and nonfarm stages, it may be concluded that vertical cooperation seems to be more appropriate for improving vertical coordination in agricultural PMChs than complete vertical integration (Mighell and Jones, 1963; Hanf and Wright, 1992). Practical evidence can be found in the increase in participation of farmers, pig traders, and slaughterhouses in chain concepts such as the IQC system and, to a lesser extent, the outdoor system for pigs in the Netherlands through the use of contracts. Complete vertical integration, however, is possible between stages with more matching scales, such as farrowing and fattening units, and large scale breeding organizations, slaughterhouses, and animal feed companies within the pork PMCh. In fact, the percentage of Dutch pig producing farms that include both a farrowing and a fattening unit increased from 22% in 1980 (Anonymous, 1991) to 26% in 1985 and to more than 30% in 1993 (Anonymous, 1994a). Improved control over product quality and quantity in general and the focus on product differentiation to supply to increasingly discriminating (niche) markets in particular, may be considered primary motivations for vertical cooperation modes in agricultural PMChs in Europe and the United States (Barry et al., 1992; Hanf and Wright, 1992). Moreover, the decline in the number of farms, the increase in farm size, the increase in vertical relationships in the non-farm sectors, and ongoing developments in EDI, I&R systems, and certification to ISO-9000 or equivalent standards (Pring, 1992), may be considered facilitating factors. The Dutch IQC system for pigs already contains some parts of the ISO standards.

Future Research

In spite of the extensive descriptive literature on the potential benefits and costs of improved vertical coordination, there seems to be little quantitative information on its effects both at the overall level of the chain and with respect to the individual stages. Although it was described how several modes of vertical cooperation, such as the IQC and the outdoor system in pig production, are currently practiced, economic quantifications of the consequences for the stages involved are rare and incomplete. More than ever these insights are needed to reveal the economics of the varying specifications, as they may be related to critical success factors determining whether a certain PMCh system can be profitable or not. Moreover, because of vertical linkages, the various stages may not only influence their own performance but also that of successive stages. Vertical linkages are defined as relationships between the way supplier or buyer activities are performed and the cost or performance of a firm's activities (Porter, 1985). A concrete practical example is provided by Hovenier et al. (1993) who conclude that unless problems on (re)distribution of expected costs and benefits among the stages of the pork chain are solved, improvement of meat quality through inclusion in the breeding goal will not be achieved. Understanding how stages interact with each other is necessary not only for improving chain efficiency but also for exposing the technical and economic consequences of product development and differentiation (Porter, 1985). Therefore, an important future contribution would be to help chain participants evaluate and quantify the costs and benefits associated with customizing output to meet end-user demands (Streeter et al., 1991) using a chain approach, acknowledging interstage relations.

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Chapter 3

COMPUTER SIMULATION OF COSTS AND BENEFITS IN A PRODUCTION-MARKETING CHAIN FOR FRESH PIGMEAT[1]

ABSTRACT

An economic chain simulation model was developed to quantify the technical and economic performance both per stage and of the pork production-marketing chain as a whole taking into account vertical linkages between the stages. The chain simulation model includes a farrowing, a fattening, and a slaughtering stage, as well as the transportation of pigs between those stages. Integral cost price analysis was the basis of the model. Input values concerned both stage and chain related biological and economic variables. Model output involved the distribution of production costs along the stages of the chain. A sensitivity analysis was carried out to show the effects of various input values on both stage and chain results. Quantification of interstage relations showed that many alternatives incurred either increased or decreased costs for all stages of the chain. Some alternatives however, caused reverse economic effects between the stages considered. For example, integration of the farrowing and fattening stage in one operation yielded benefits for the farm stages while higher - transportation - costs were incurred in the slaughtering stage.

3.1 INTRODUCTION

Current system simulation models in pork production primarily focus on a single farm or agribusiness firm (Jalvingh, 1992). The process of converting 'genetic material' into final pigmeat products, however, is performed by a successive chain of mutually dependent farms and agribusiness firms, so-called pork production-marketing chains (Den Ouden et al., 1996). An important characteristic of production-marketing chains is that their stages are interlinked vertically (Dalton, 1982). Vertical linkages are relationships between the way in which supplier or buyer activities are performed and the cost or performance of a firm's activities (Porter, 1985). Although in the literature the potential benefits of vertical cooperation and the importance of integral analyses are recognized (Porter, 1985), published calculations are rare, if any (Den Ouden et al., 1996). However, in order to optimize and control - end-product - efficacy and production efficiency, it is necessary to gain insight into the economics of the stages of the chain both separately and in interaction

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[1] paper by Den Ouden, M., Huirne, R.B.M., Dijkhuizen, A.A. and Renkema, J.A. submitted for publication to *Agricultural Systems*.

with each other. In achieving higher efficiency or higher value, costs may be deliberately raised in one stage of the chain in order to accomplish a greater decrease of costs or a higher value in another stage of the chain. In this paper, a pork chain model is presented including a farrowing stage producing feeder pigs, a fattening stage producing hogs, and a slaughtering stage. Transportation of feeder pigs and fattened pigs is also taken into consideration.

The objective of this paper is to describe the components and behaviour of a pork chain model that simulates technical and economic output in relation to both intra- and interstage effects on performance and profitability. Integral cost price analysis was the basis of the chain model. Special attention was focused on the quantification of interstage relations and - their effect on - the distribution of costs and benefits over the stages of the chain. The model was also used to compare management strategies with respect to their effect on stage and chain performance.

3.2 MATERIAL AND METHODS

3.2.1 General scope

In general the pork chain simulation model consists of four stages including farrowing, fattening, transportation and slaughtering of pigs. The general outline of the model is presented in Figure 3.1. In the farrowing stage feeder pigs are produced which are transferred to the fattening stage at a live weight of 23 kilograms. Pig farrowing and fattening can either be specialized in separate stages or be integrated into one farrow-to-finish operation. As the integration of the two pig farming stages is optional, so is the transportation of feeder pigs which is redundant in case of integration in one farrow-to-finish operation. In the fattening stage the feeder pigs are grown and finished (hogs). At a live weight of approximately 108 kilograms the fattened pigs are transported to the slaughterhouse where they are slaughtered and either sold as carcasses or processed further and sold in parts.

In its basic form, the model is deterministic, using some static or fixed probability distributions however. Three types of variables were distinguished in the model: input variables, variables representing interstage relations and output variables. Variables can involve biological or technical parameters or economic factors. They can concern stage-specific aspects or chain issues, relating to more than one stage. A variable controlling interstage relations can be an input variable, or a technical output variable calculated by the model. An example of a technical interstage relation in the model is represented in the linkage between the fattening stage and the slaughterhouse. Probability distributions were used to distribute the saleable hogs over live weight classes. Live weights are directly related to carcass weights via the dressing percentage. At their turn, carcass weight classes correspond to various quality classes used within the slaughterhouse. As a result of this interstage relation, a change of the delivering strategy in the fattening stage influenced both the rate of turnover and economic results in that stage and economic results in the slaughtering stage. 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. The model is programmed in the Turbo Pascal language (Borland, 1989), and is suitable to run on a personal computer.

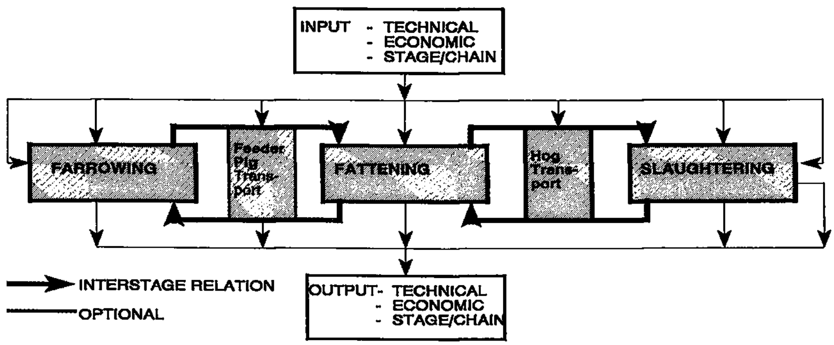


Figure 3.1 General outline of the pork chain simulation model.

Costs were calculated as opportunity costs, representing the potential benefit that was given up when one application of an asset was preferred over another (Barfield et al., 1991). They are presented on an animal basis, i.e. per feeder pig sold (farrowing stage), per hog sold (fattening stage) and per hog slaughtered and sold (slaughtering stage). However, evaluations on a farm or firm basis or per kg of end product sold, are also optional. Costs are summarized in various categories such as interest, depreciation, labour costs, feed costs, and other costs. They can vary proportionally with the scale of operation, or remain constant over a specified range of activities. Examples of the latter type included management labour costs, cost of housing and transportation facilities, and certain overhead expenses. Feed costs probably form the most common example of costs which vary in direct proportion with the scale of operation. With respect to the farrowing and the fattening stages, the efficient scale of operation was based on the number of animals (sows and hogs respectively) that one skilled worker, or full time equivalent (f.t.e.), can handle within a regular number of working hours per year. Regarding the slaughtering stage it was assumed that the efficient scale of operation equalled a slaughter capacity of 300 to 400 pigs slaughtered per hour (Product Board for Livestock and Meat, 1991). The way in which the various cost components per stage were calculated is described in the following sections.

3.2.2 Farrowing stage

Input values that characterize the farrowing stage in the default situation, and input values used for sensitivity analyses in a later section ('low' and 'high' and 'breed types') are summarized in Table 3.1. An important group of input variables within the farrowing stage included the variables concerning reproduction, culling and replacement. Based on a gestation period of 115 days, a lactation period of 28 days and an interval of 8 days from weaning till first breeding, a sow's production cycle was at least 151 days in the default situation (Table 3.1). However, because of sows that failed to conceive early or at all after 3 breedings (Table 3.1), the average production cycle was longer. Input figures on the distribution over culling reasons other than failing to conceive and on the corresponding average moment of culling, were taken from Dijkhuizen et al. (1989) and used to calculate the annual culling rate. Culled sows were replaced by gilts, of which the majority was assumed to be bought at a mature age of approximately 6.5 months. Total culling of mature gilts accounted for 10% (Table 3.1) until first insemination at an age of 231 days. In this way, the number of replacement gilts that had to be bought per sow per year could be calculated. Moreover, these input values were used to calculate the distribution of sows over the various stages of a production cycle, corresponding to so-called 'sow categories'. The various categories of animals were related to the amount of labour needed (Appendix 3.I) and the required number of different housing pens of the sow barn. In the default situation, open and pregnant sows were tethered. Lactating sows with suckling piglets were housed in nursery pens in the farrowing area. After weaning, piglets could be housed in the farrowing area or in separate rearing pens. Of the 10.8 piglets born alive per litter, 13.2% died before weaning. From weaning till the moment the piglets were sold (70 days of age), another 1.5% were lost, adding up to a total mortality rate of 14.5% (Table 3.1). Together with the farm lay-out, in terms of housing facilities and feeding system, these input variables determined the occupation rate of buildings and the amount of labour needed per sow per year. Assuming a total number of 2348 working hours available per f.t.e. per year (Anonymous, 1992a), the latter was used in calculating the efficient scale of the farrowing operation and following, the total number of feeder pigs sold per year.

Table 3.1 Major technical and economic input values of the farrowing stage

				breed types	
Variable	Default	Low	High	White	Meat
Min. duration of a sow's cycle (days)	151				
Max. no. of breedings per production cycle	3	2	4		
Probability of conception (%)[1]	85/65/50/40	68/52/40/32	100/-/-/-		
Litter size (piglets born alive)	10.8	8.6	13.0	10.2	10.4
Piglet pre-weaning mortality rate (%)	13.2			10.5	9.5
Piglet post-weaning mortality rate (%)	1.5			1.5	2.2
Weight at which feeder pigs are sold (kg)	23				
Culling rate of young & mature gilts resp. (%)	25/10				
Feed for sows (Energy Value (EV[2]) per day)					
- gestation (days 1-60/61-85/86-farrowing)	2.3/2.7/3.2				
- lactation (per sow/extra EV per piglet)	1.75/0.5				
- weaning - first service	3.5				
- first service -gestation	2.3				
Price mature replacement gilt (Dfl./head)					
Price feed (Dfl./100 kg)	520	415	625		
- piglets	66.4	53.1	79.7		
- non-lactating sows (EV/kg=0.97)	42.1	33.7	50.5		
- gilts, lactating sows & boars (EV/kg=1.03)	46.4	37.1	55.6		
Feeder pig price (Dfl./head)	107.6	86.1	129.1		

[1] Probability of conception at 1st, 2nd, 3rd, and 4th insemination resp. (Huirne et al., 1992).
[2] EV/kg=1=8786 kJ net-energy for fat production.

In the default situation, the animals were fed automatically, saving considerable labour time (Appendix 3.I). Besides fully-automated systems, including computerized feeding, also semi-automated feeding systems, using so-called 'feed augers', and non-automated feeding is optional. The amount of feed consumed per animal was derived using a standard ration with an average energy content (Table 3.1). The daily standard ration of energy (EV) per pig depended on age, live weight and stage in the production cycle (CVB, 1991). Up to a feeder pig age of 70 days (live weight of 23 kg) piglets were assumed to consume 25 kg of feed in total.

Both within and between pig populations of different breeds, there is genetic variation in performance traits such as litter size, growth rate, feed intake and lean meat percentage. Breeding companies aim at exploiting these variations via selection and cross breeding in order to improve pig performance with respect to one or more traits. As such, breeding influences form an important interstage relation affecting performances in many stages of the pork production-marketing chain (Hovenier, 1993). To present an example of this interstage relation, the results of a trial performed at the Stotfold pig development unit were used (Anonymous, 1989). This trial was designed to compare the performance of the progeny of Meat type sires with that of conventional White sires under the same conditions. The overall means used in this study are presented in Tables 3.1, 3.2 and 3.3 (Anonymous, 1989).

3.2.3 Fattening stage

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 lower use of feed per kg of live weight gain when the growth rate increases. Growth rate was assumed to be normally distributed with a standard deviation of approximately 10% of the average growth rate (Table 3.2).

Table 3.2 Major technical and economic input values of the fattening stage

Variable	De-fault	Low	High	breed types[1]		feed Auspig[2]	
				White	Meat	basis	high EV
Av. growth rate (grams/day)	719	650	790	687	676	750	825
Std. dev. growth rate (%)	10	8%	12%				
Feed conversion ratio	model[3]	model[3]	mod[3]	2.50	2.55	2.60	2.28
Mortality rate (%)	2.1						
Number of deliveries per cycle	2	1	3[4]				
Distr. pigs 1st/2nd delivery (%)	20/80	10/90	30/70				
No. of pens per room	8	6	10				
Prices (Dfl./100 kg):							
- start feed (EV[5]/kg=1.08)	53.6	42.9	64.3			53.5	56.0
- growing feed (EV/kg=1.08)	46.6	37.3	55.9			42.9	51.3
- finishing feed (EV/kg=1.08)	44.7	35.8	53.7				49.2
Meat price (Dfl./kg carcass)	3.41	2.73	4.09				

1 Refers to results of the Stotfold pig development unit in comparing different breed types.

2 Results of the AUSPIG simulation model (Black, 1986, 1988) for two feeding strategies. Not included in Table 3.2 but also considered in the evaluation of the economic effects of the AUSPIG results was an average higher lean meat content (+0.6%-points) of the carcasses of the pigs fed with the high energy feeds.

3 Calculated by the simulation model.

4 In case fattened pigs per room were delivered to the slaughterhouse in three times, the relative distribution over the 1st, 2nd and 3rd delivery equalled respectively 10%, 20% and 70%.

5 EV/kg=1 =8786 kJ net-energy for fat production.

In the default situation, pigs were delivered to the slaughterhouse in two batches. Per room, the 20% fastest growing pigs were sold first, whereas the remaining 80% were delivered in the second group. Assuming the all-in-all-out system, the length of the fattening period of the pigs that were sold last expanded with three days needed for cleaning and disinfection of rooms determined the number of production cycles realized per year. In addition, the occupation rate of hog places was calculated. The latter also depended on the assumed loss rate of hogs, equalling 2.1% in the default situation. Mortality of hogs was assumed to take place in the model halfway during the fattening period.

Together with the fattening farm lay-out, the number of production cycles per year were used to calculate the working hours needed per hog (Appendix 3.I). Similar to the feeding of sows, fattening pigs were also assumed to be fed automatically. Depending on the daily growth rate of hogs in the range from 23 to 108 kg of live weight, the daily EV consumption increased from approximately 1 EV to 3 EV (CVB, 1991). The model allows hogs to be fed two or three different types of feed during this period.

Major pig production characteristics such as daily gain, feed conversion ratio and body composition are influenced, among others, by feed aspects such as feed ingredients and feeding regimes. AUSPIG is a powerful computer package that simulates pigs' biological performance in respect to variables such as the pigs' diet, genotype, housing and environment (Black et al., 1986). It was used to present an example of the interstage relation between feed formulation and pig performance in other stages of the pork chain. The biological effects of two feeding strategies were simulated including a standard fattening pig diet consisting of two feed types (EV of 1.14 and 1.10) and a specific high energy diet involving three feeds with energy values of respectively 1.18, 1.18 and 1.25. The results are presented in Table 3.2. They will serve as input values used for a sensitivity analysis concerning interstage relations.

3.2.4 Slaughtering stage

In contrast to the relatively large amount of information on economics of the farrowing and fattening stages in terms of both empirical data (see for instance Dijkhuizen et al., 1989; Anonymous, 1992b) and normative calculations (see for instance Singh, 1986; Pomar et al., 1991; Huirne et al., 1992; Jalvingh et al., 1992), published data or calculations on the slaughtering stage are hardly available. This may be explained by the high level of concentration (Perry, 1989) in this industry combined with overcapacity (Den Ouden et al., 1996; Product Board for Livestock and Meat, 1991). Therefore, data needed for the model with respect to the slaughtering stage were obtained from experts' opinions. Major input values characterizing the slaughtering stage, as well as input values used for sensitivity analyses, are summarized in Table 3.3.

A capacity of 400 pigs slaughtered per hour was assumed (Table 3.3). With 250 slaughtering days per year and 8 hours per day, this resulted in a capacity of 800,000 pigs slaughtered per year. The occupation rate was set at 94%. In the slaughtering stage the following processes can be distinguished: supply of hogs, slaughtering, cutting of carcasses, and sale and expedition of end-products. During unloading the truck, the supplied hogs are subjected to visual inspection. Hogs that fail in this respect are slaughtered at the expense of the farmer at a separate slaughterline (Table 3.3).

Table 3.3 Input values of transportation of hogs and slaughtering

Variable	Default	Low	High
Slaughter capacity (pigs per hour)	400		
Pigs condemned ante mortem inspection (%)	1.5	1.2	1.8
Boars supplied (%)	2.0		
Average slaughter efficiency (%)	77		
Average carcass weight (kg)[1]	83	75	91
Pigs without pathological lesions (%)	79	63	95
Relative distribution pathological lesions (%)			
- Pleurisy	48		
- Abscesses 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	10:90	50:50
Slaughtering labour (Dfl./hour)	32.5		
Meat price carcass (kg)	4.0		
Meat price average cut (kg)	4.3		

[1] The average carcass weight of the various breed types in the Stotfold trial equalled 63 kg.

During slaughtering, the national meat inspection service carries out post mortem examination of carcasses. Carcasses with major pathological lesions are separated in order to remove or correct affected parts. After a reinspection, those carcasses are either put back in line or fail meat inspection again and will be condemned totally. Definitions of the pathological lesions were described by Elbers (1991). In the default situation, 79% of the carcasses is assumed to be without any lesion. The relative distribution over the various pathological lesions detected on the remaining carcasses is presented in Table 3.3.

The weight of the carcasses is related to the live weight of the animals via the slaughter efficiency (Table 3.3). As described earlier, the standard deviation in growth rate and the delivering strategy of the farmer (fattening stage), determine the relative distribution of the supplied pigs over live weight classes. This link between fattening and slaughtering stage represented an important interstage relation. In turn, carcass weight is related to lean meat percentage and classes of overall body composition of the carcass. Three classes were distinguished: C&B (bad), A (average) and AA (good) (Dijkhuizen et al., 1996). Generally, if the carcass weight increases, the lean meat percentage of the carcass decreases. The percentage of pigs in class 'AA' (good) was highest in the carcass weight ranging from 83 to 95 kilograms. Currently, these three characteristics (carcass weight, lean meat percentage and body composition class) represent the most important quality parameters of the carcass used in payment systems for Dutch farmers. Moreover, within the slaughterhouse these characteristics are used to allocate carcasses to quality classes, by means of the internal quality system. Based on demand specifications, the quality classes, including the EU SEUROP classification, are related to the processing options of the carcasses and thereby to the value of the end-products (Dijkhuizen et al., 1996).

After slaughtering, slaughter by-products, such as the head, are removed and the carcass is refrigerated. After refrigerating, carcasses can either be sold directly or be cut further and sold in parts. The cutting of carcasses into parts is quite labour-intensive. Labour requirements are presented in Appendix 3.I. Moreover, further processed end-products (parts) cause higher expedition costs.

3.2.5 Pig transportation

In case of separate specialized farrowing and finishing operations (default), transportation of feeder pigs to the fattening farms was assumed to take place at the expense of the fattening stage. Similarly, the costs of transporting fattened pigs to the slaughterhouse were assumed to be incurred by the slaughtering stage. Input values used to characterize feeder pig and fattened pig transportation are presented in Table 3.4. Although no specific interstage relation was defined concerning pig transportation, transportation costs per animal were influenced by the output of both the farrowing and the fattening stage as is described in the following section. Transportation of fattened pigs resembles transportation of feeder pigs; therefore only the latter is described below. The only difference refers to unloading at one place (slaughterhouse) instead of at several fattening farms.

Table 3.4 Technical and economic input values of transport of feeder pigs and hogs.

Variable	Default feeder pigs	Default fattened pigs	Low	High
Stock density truck (kg live weight/m^2)	190	300		
Occupation rate truck (%)	90	90	80	100
Distance covered per drive (km)	125	175		
Pigs transported per firm per year (x 1000)	1,000	750		
Transportation truck characteristics				
- investment (x 1000 Dfl./truck)	296	273		
- net transportation surface (m^2)	34.5	53		
- net driving speed (km/hour)	60	65		

Feeder pigs could be delivered to the fattening farm approximately once a week, which is common practice. The exact duration of this delivery interval, however, depends on the delivery schedule of hogs to the slaughterhouse. Together with the scale of the sow farm, the delivery interval was used to calculate the number of feeder pigs that was available for sale per delivery. Input on the legally prescribed stock density (Table 3.4), the average live weight, and the net transportation surface, determined the loading capacity of the truck, approximating 285 feeder pigs or 145 fattened pigs. Truck loading capacity, occupation rate of the truck (Table 3.4) and the number of pigs available for transportation gave the number of farms that had to be visited in order to load the truck. The number of farrowing and fattening farms to be visited, was related to the time needed for loading and unloading. Combined with input on the average driving speed, the daily driving hours, and on the number of feeder pigs transported annually, it was calculated how many trucks were needed for annual transportation. By adding total overhead expenses of the transportation firm, the transportation costs per feeder pig were obtained.

From a Dutch research project on Integral Quality Control in the pork production-marketing chain, it was concluded that the number of feeder pig suppliers of a fattening farm influenced the performance of the fattening and slaughtering stages (Elbers, 1991). Effects on average daily growth rate, mortality rate, number of fattening cycles without the use of drugs, relative distribution of drug use over individual and group treatments, and effects on the prevalence of pathological lesions were quantified. The effects of these interstage relations are presented in Table 3.5.

Table 3.5 The effect of the number of feeder pig suppliers per fattening farm on fattening performance and percentage of hogs without any slaughter deviation as found in the slaughtering stage (Elbers, 1991).

origin of feeder pigs	%	growth rate (gram/ day)	morta-lity rate (%)	without any lesions (%)[1]	% of drug free fattening cycles	distribution of drug treatments		
						group	indiv	both
farrow-to-finish	36%	731	1.2	78	20.2	5.7	57.6	36.7
1 supplier	31%	719	1.1	79	10.5	3.5	56.3	40.2
2 suppliers	18%	707	1.7	73	7.8	3.4	43.9	52.7
≥ 3 suppliers	15%	693	2.0	68	4.0	6.0	40.0	54.0

[1] Not found in Elbers (1991) but own estimations

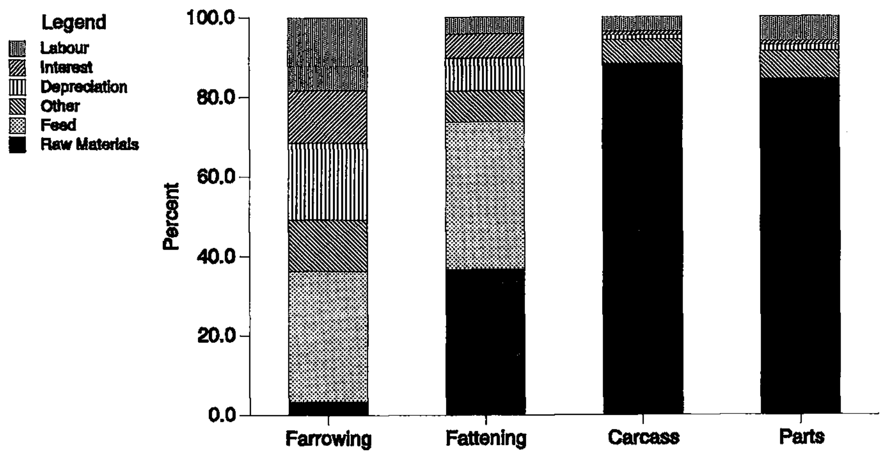
Because some cost components are common to all stages or are related to farm business in general, this section combines the description of their default input values (Appendix 3.II). General farm costs included car expenses, financial accounting and administration, telephone, farm insurance and farm clothing. On an animal place basis, general costs included insurance and indirect taxes (Anonymous, 1992b). The price of labour was set at Dfl. 32.5 per hour. The interest rate at which the use of capital was charged equalled 9.3% in the default situation. Interest was calculated on the average investment value of fixed assets as well as on live animals, feed inventory and cash money (current assets). The annual depreciation rates of buildings and equipment used in the stages of the chain varied from about 4% to 20% and are presented in Appendix 3.II.

3.3 RESULTS

3.3.1 Basic situation

Based on the default input values for the farrowing stage described in the previous section sows produced on average 2.29 litters per year resulting in 21.1 feeder pigs sold per sow per year. Within the fattening stage 2.94 production cycles per year were realized. The integral cost price analysis resulted in production costs of Dfl. 120 per feeder pig sold, while the cost price per hog sold equalled Dfl. 189. The total production costs per hog sold to the slaughterhouse, therefore, equalled Dfl. 309 from farrow to finish. Total cost of slaughtering hogs and selling them as either carcasses or in parts ('cuts') equalled Dfl. 38 and Dfl. 52 respectively. The higher cost of processing and selling cuts instead of carcasses mainly resulted from the additional labour. In Figure 3.2, the distribution of the overall cost price, including raw material costs, over the various cost components is presented per feeder pig sold, per hog sold and per carcass or combination of parts sold.

As shown in Figure 3.2, feed costs were the major cost components in both the farrowing and the fattening stage, representing 34% and 59% of the total production costs per feeder pig and per hog respectively and 33% and 37% of the overall cost prices including raw materials. Owing to the lack of land to produce feed products of one's own, Dutch pig farmers, in general, have to buy all the feed. The farrowing stage was relatively labour-intensive compared with the more capital-intensive fattening stage. Also the slaughtering stage involved high labour costs relative to total production costs. In Figure 3.2, cost of artificial insemination and cost of replacement gilts reduced by the value of culled sows and culled replacement gilts were considered raw material costs for the farrowing stage, adding up to a total of Dfl. 4 per feeder pig sold. Similarly, feeder pigs and hogs represented the raw material input for the fattening stage and the slaughtering stage respectively. All raw material costs presented in Figure 3.2 were based on average 1992 market prices, presented in Tables 3.1, 3.2 and 3.3. Raw material costs proved to have a big impact on the overall costs of fattening pigs and slaughtering pigs in particular. Comparable figures of the composition of the slaughtering cost price were described by Lorenz (1991), who also considered the raw material costs the major cost component in the slaughtering stage.



Raw Materials	4.0	109.9	282.8	282.8
Feed	39.5	111.1	0.0	0.0
Other	15.5	23.4	19.8	22.9
Depreciation	23.2	24.1	3.6	5.3
Interest	15.7	18.4	2.9	3.7
Labour	21.9	12.5	11.9	20.3

Figure 3.2 Relative (in graph) and absolute (Dfl./head (in table)) cost composition of feeder pigs (farrowing stage), fattening pigs (fattening stage), carcasses and cuts (slaughtering stage).

Selling 21.11 feeder pigs per sow per year at a farm scale of 165 sows, the net return to labour and management (i.e. the farm income)[2] of the farrowing stage, equalled Dfl. 61,568. Similarly, it was calculated that the annual output of hogs equalled 6130, yielding a farm income for the fattening stage of Dfl. 36,524. Per full time equivalent (f.t.e.) in the slaughtering stage, 2760 hogs were slaughtered and sold per year. Selling 30% of the slaughtered hogs as carcasses and 70% in parts, the net return to labour and management per f.t.e of the slaughtering stage therefore equalled Dfl. 38,173.

[2] Annual income is defined as the returns per pig minus all costs per pig except labour costs and the difference between calculated and paid interest per pig, multiplied by the total annual number of pigs sold or slaughtered per farm respectively f.t.e.

3.3.2 Sensitivity analysis single stages

The influences of changes of various technical input values on the output of the stages are summarized per stage in Tables 3.6 to 3.9. Table 3.10 combines the effects of changes in economic input in the chain. Most alternatives concern input values at a 20% lower (low) or 20% higher (high) level than the values in the default situation (Tables 3.1 to 3.4).

3.3.2.1 Farrowing stage

If 2 instead of 3 inseminations per sow per cycle were allowed, more sows were culled due to failing to conceive, increasing the annual culling rate by 6 percentage points from 40% to 46% (Table 3.6). Because the length of a production cycle decreased, more litters were produced per sow per year and 0.05 more feeder pigs were sold. However, during the production cycle, a sow spent relatively less time in the breeding area and more time in the farrowing room, causing an increase of labour costs, housing costs and feed costs. Moreover, the number of sows per f.t.e. was reduced by 1 sow to 164 sows instead of 165 sows in the default situation. In general, the production cost increased by Dfl. 0.5 per feeder pig sold and the annual farm income declined by Dfl. 1,679.

For reasons similar to the latter case, also in the case of lower farrowing rates, the annual culling rate was increased (by 14.1 percentage points, Table 3.6). However, as the average period between weaning and conception increased, the length of a production cycle was now increased instead of decreased.

Table 3.6 Results of the farrowing stage when the 'low/high' input variables are used according to Table 3.1. Output values are presented as the difference from the default situation (in brackets).

	Scale (165 sows)		Pigs sold pspy (21.11)		Culling rate (40%)		Cost price (Dfl. 119.7)		Farm income (Dfl. 61,568)	
Alternatives	low	high	low	high	low	high	low	high	low	high
# Breedings	-1.0	+0.4	+0.05	-0.03	+6.0	-2.4	+0.5	-0.1	-1,679	+489
Farrowing rate	-1.4	+0.3	-0.98	+0.70	+14.1	-6.0	+6.0	-3.5	-17,511	+11,048
Litter size	0	0	-4.30	+4.30	0	0	+24.9	-16.4	-60,652	+60,522
Non-automated	-37.9		0		0		+6.0		-13,162	
Piglet housing[1]	+6.6		0		0		+1.7		-5,603	

[1] In the default situation weaned piglets are transferred from the nursery pen to a separate rearing pen with fully-slatted floors. In this alternative, weaned piglets are not removed from the nursery pen, but stay there until selling.

As a result, the number of litters produced per sow per year dropped from 2.29 to 2.18, reducing the number of feeder pigs sold per sow per year with almost 1 (Table 3.6).

The biggest effect on feeder pig production costs was caused by the litter size, which proved to be a major input variable of the farrowing stage. When the litter size was decreased by 20%, the production costs per feeder pig changed more (i.e. Dfl. 24.9) than was the case when litter size was increased by 20% (i.e. Dfl. 16.4). This was caused by the fact that labour and housing variables depended on the number of litters produced rather than on litter size. As a result, the labour and housing costs per sow per year remained unchanged when the litter size altered. Moreover, the amount of gestation feed consumed by sows was assumed to stay the same. In terms of absolute quantity, the farm income changed more or less equally by altering the litter size in equal proportions.

When feeding of sows, boars and weaned piglets was a non-automatic activity rather than a fully-automated system, labour per sow per year increased by 30%, causing the number of sows per f.t.e. to drop from 165 to 127 (Table 3.6). Consequently, labour costs increased by Dfl. 137.5 per sow per year. Without the investment in feed automation, the housing costs per sow per year decreased by 5%. However, because the investment in buildings varied disproportionately with the number of sows present, the relative decrease in housing costs tumbled to 3.3%, equalling Dfl. 24 per sow per year. In general, production costs per feeder pig increased by Dfl. 6.0. Because increased labour costs were the main cause of this, farm income per year decreased by Dfl. 13,162 (Table 3.6).

Rearing weaned piglets in nursery pens instead of in separate fully-slatted rearing pens reduced overall labour per sow per year by 4%, causing the number of sows per f.t.e. to increase by 6.6. Labour involved in transferring weaned piglets to the rearing pens and in cleaning and disinfecting the nursery room after weaning were ignored. However, due to the longer time required for cleaning and disinfecting the half-slatted nursery pens instead of the fully-slatted rearing pens, the labour needed per litter piglets slightly increased (Appendix 3.I). The average investment per sow place increased by 9%. However, without cleaning the nursery pen between weaning and rearing, the occupation rate slightly increased, causing the cost of housing per sow per year to increase by only 7%. In total, the production costs per feeder pig sold increased by Dfl. 1.7 while farm income reduced by Dfl. 5,603.

3.3.2.2 Fattening stage

Changes in daily growth rate had a major impact on the rate of turnover per hog place in the fattening stage. Table 3.7 shows the effects of a 10% increase in growth rate, causing the number of fattening cycles to rise from 2.94 to 3.22 (+0.28) per year. As a result, relatively more time was spent each year on cleaning and disinfecting the rooms after delivering the hogs for sale. This caused the occupation rate of the hog places to decline by 0.2 percentage points from 93.9% to 93.7%. Although per pig sold the labour required declined, activities had to be carried out within a shorter period of the fattening cycle, causing the average number of animals that could be handled to decline by 81.3 (Table 3.7). However, the larger number of fattening cycles caused the number of hogs sold per year to rise from 6,130 to 6,462. Because daily gain is related to the feed conversion ratio, the latter decreased from 2.80 to 2.72. Per hog sold, the production costs were reduced by Dfl. 8.02, while on farm basis, the net income increased by Dfl. 43,633 per year.

Reducing the variation in daily gain, the number of deliveries per room, and the percentage of hogs that were sold first caused the number of fattening cycles produced per year to increase by 0.01, 0.09 and 0.04 respectively (Table 3.7). The length of a production cycle was determined by the time needed to reach the desired live weight based on the average growth rate of the slowest growing hogs, i.e. the hogs that were sold last in the second or third delivery. Since the variation in daily gain diminished, the average growth rate of the 80% hogs sold last increased. Moreover, the period between the first and the last delivery of hogs per compartment reduced from 16.5 days to 13.4 days, causing the occupation rate to increase by 0.5%.

Table 3.7 Results of the fattening stage when the 'low/high' input values are used according to Table 3.2. Output values are presented as the difference from the default situation (in brackets).

	Scale (2000 hogs)		# Production cycles (2.94)		Occupation rate (93.9%)		Cost price (Dfl. 189.45)		Farm income (Dfl. 36,524)	
Alternatives	low	high	low	high	low	high	low	high	low	high
Growth rate[1]	+86.4	-81.3	-0.28	+0.28	+0.3	-0.2	+11.13	-8.02	-55,497	+43,633
Std. growth	+0.92	-0.68	+0.01	-0.01	+0.5	-0.4	-0.16	+0.27	+10,084	-10,662
No. deliveries	+20.8	-20.0	+0.09	-0.04	+2.6	-1.2	-2.03	+0.68	-3,591	+1,561
Dist.deliveries	+1.82	-0.85	+0.04	-0.04	+1.2	-1.0	-0.44	+0.58	-1,467	+1,883
No. of pens	-66.7	+42.4	0	0	0	0	+5.11	-2.95	-25,717	+15,627
Semi-automat.	-534.15		0		0		+0.98		+4,694	
Non-automated	-795.33		0		0		+4.71		-2,912	

[1] The input values of the daily growth rate varied by -10% (low) and +10% (high).

The fewer hogs were sold in the first group, the fewer hog places remained unoccupied during the rest of the fattening cycle. Occupation rates increased by 3.2 and 1.2 percentage points when 10% instead of 20% of the hogs were delivered in the first group, and when one rather than two deliveries took place per room (Table 3.7).

A lower meat price was paid for hogs with a carcass weight below 76 kg or over 99 kg. Reducing the variation in daily gain, increasing the number of deliveries per room and raising the percentage of hogs that were sold first, caused the percentage of hogs that fall in the range of 76 to 99 kg to increase from 91% in the default situation to approximately 93% to 95%. As a result, the average return per hog sold increased. It is emphasized here that the model simulated rather than optimized alternatives.

If rooms consisted of 6 instead of 8 pens, the labour spent per hog sold increased. This can be explained by the activities that are related to a room. As a result, the scale of the fattening stage was reduced by 66.7 hogs. Moreover, the investment per hog place increased if smaller, and, therefore, more rooms had to be built. Scale of operation and investment were also influenced by the type of feeding system. When the feeding system was changed from automated feeding to semi-automated or even non-automated feeding, labour required for feeding the hogs increased, causing the scale of fattening to reduce by 27% and 40% respectively (Table 3.7). As a result, production costs increased by Dfl. 0.98 and Dfl. 4.71 per hog sold respectively. In the first case, this increase was caused mainly by higher labour costs, resulting in a net increase of the farm income. In the latter case however, total scale diseconomies caused the farm income to decrease by Dfl. 2,912.

3.3.2.3 Slaughtering stage

When the percentage of pigs that failed ante mortem visual inspection was decreased by 20%, the average buying price per pig increased by Dfl. 0.20. Selling the pork, the returns increased by Dfl. 0.50 however (Table 3.8). Because this alternative involves only a small number of pigs, the effects on labour costs and total slaughtering and processing costs are negligible. As a result the return per f.t.e. increased by approximately Dfl. 760 (Table 3.8).

When the average carcass weight dropped with 10% from 83 kg to 75 kg, the average buying price per pig decreased by Dfl. 36.1. Almost 25% of this decrease resulted from carcass weight discounts and lower premiums paid for the relatively higher lean meat content of the carcass. As a result, the decrease in buying price exceeded the decrease in average returns (Dfl. 34.6 (Table 3.8)). Because more carcasses failed the specifications of the carcass demand, they had to be allocated to lower value destinations and cut into parts. As a result, labour and other slaughtering and processing costs increased. The higher labour expenses were the main reason of the increase in return to labour and management per f.t.e. (Table 3.8). The net result per f.t.e. remained unchanged, however, compared with the default situation.

Table 3.8 Results of the slaughtering stage when the 'low/high' input values are used according to Table 3.3. Output values are presented as the difference from the default situation (in brackets).

	Labour costs/hog (Dfl. 17.9)		Slaughtering & processing costs/hog (Dfl. 48.2)		Returns/ carcass:parts (Dfl. 326.2)		Return to management/f.t.e. (Dfl. 38,173)	
Alternatives	low	high	low	high	low	high	low	high
% condemned ante mortem	0	0	0	0	+0.5	-0.5	+760	-744
average carcass weight[1]	+1.0	+0.3	+1.5	+0.8	-34.6	+31.5	+2,895	+16,105
% no pathological lesions	+0.04	-0.04	+0.1	-0.1	-0.3	+0.3	-942	+944
Ratio carcass : parts	+1.7	-1.95	+2.8	-3.3	+3.2	-3.7	+5,805	-6,678

[1] Alternative carcass weights were varied by -10% (low) or +10% (high).

When the percentage of hogs with pathological lesions increased, more labour was needed to correct or remove those lesions. As a result, the labour costs per - average - hog slaughtered, slightly increased by Dfl. 0.04 (Table 3.8). Moreover, a higher percentage of carcasses had to be sold at a lower value. As a result, slaughtering and processing costs per hog increased, and the average returns per carcass or parts sold decreased. Consequently, also the returns to labour and management per f.t.e. dropped by Dfl. 942 (Table 3.8). Cutting carcasses into primary parts is a labour-intensive activity. Decreasing the ratio of carcasses to parts sold from 30:70 to 10:90, therefore, resulted in an increase in labour costs per average hog slaughtered and processed (Dfl. 1.66). The average revenue of the meat sold, however, increased by Dfl. 3.2, resulting in an overall net increase of the returns to labour and management per f.t.e.

3.3.2.4 Transportation

When the number of feeder pigs supplied per farm (Table 3.9) was reduced from about 80 in the default situation to 63, more farms had to be visited to load the truck. As a result, the number of drives the truck was able to make each day decreased by 0.13, which made 0.35 more trucks necessary to transport the annual number of feeder pigs. The transportation costs per feeder pig increased by Dfl. 0.05. Comparable results were obtained when the number of feeder pigs demanded per fattening farm, was reduced. Similarly, reverse results were obtained when the number of animals supplied or demanded per farm was increased. Transportation costs per animal were most influenced, however, by changes in the occupation rate of the truck. A decline in the occupation rate of the truck by 10% caused the transportation costs of a feeder pig to increase by 4%, while the costs of hog transportation increased by 6% (Dfl. 0.23 in Table 3.9).

Table 3.9 Results of pig transportation when the 'low/high' input variables are used according to Table 3.4. Output values are presented as the difference from the default situation (in brackets).

	No. of drives/day (2.5 - 2.5)[1]		No. of trucks/year (6.2 - 6.6)[1]		Transporting costs (2.30 - 3.63)[1]	
Alternatives	low	high	low	high	low	high
Supply feeder pigs/time unit[2]	-0.13	+0.07	+0.35	-0.17	+0.05	-0.03
Demand feeder pigs/time unit[3]	-0.13	+0.07	+0.35	-0.16	+0.05	-0.02
Occupation rate (feeder pigs)[4]	+0.20	-0.19	+0.27	-0.16	+0.10	-0.07
Supply fattened pigs/time unit[2]	-0.05	+0.12	+0.12	-0.28	+0.03	-0.08
Occupation rate (fattened pigs)	+0.20	-0.15	+0.24	-0.25	+0.23	-0.20

[1] The first figure refers to the default result of the feeder pig transportation, while the second figure relates to the default result of the hog transportation.
[2] Technical output variable instead of input variable.
[3] The number of feeder pigs demanded depended on the number of pens per fattening room.
[4] The occupation rates of the trucks were varied by -10% (low) and +10% (high).

3.3.3 Sensitivity analyses economic input values all stages

As the down- (-20%) and upward (+20%) changes in economic input values had the same but opposite effects on the cost prices and annual incomes per stage, only results of the lower (-20%) changes are presented in Table 3.10. Economic input values concerning labour and capital costs and prices, did not influence technical output, and therefore did not affect the technical performance of the sow herd, the fattening herd, transportation or the slaughterhouse as such. Of course, costs and income were influenced by changes in these variables (Table 3.10). In contrast to the fattening stage, changes in labour costs had a bigger impact on the economics of the labour intensive farrowing and slaughtering stages than similar changes in the interest rate. This also applied to the cost of transportation, the results of which were included in the production costs and income changes of the fattening and the slaughtering stage. Changes in feed prices and feeder pig prices had a large effect on the sow and fattening farm income. Since the feeder pig price was used to calculate the interest on hogs, changes in feeder pig prices resulted in small changes in fattening costs (Table 3.10). Fattening farm income and income per f.t.e. at the slaughterhouse were most influenced by changes in meat price. Changes in feed prices and feeder pig prices had a smaller effect on the fattening farm income. Nevertheless, these smaller effects were still far larger than the effect of changes in the technical input values. In practice, prices of various pork products are related to each other as a result of which the effect of higher output prices will be (partly) compensated by increasing input prices. The effects presented in Table 3.10 are additive in this respect.

Table 3.10 Results of each stage of the chain when the 'low' (-20%) input values of economic variables are used according to Tables 3.1, 3.2 and 3.3. Output values are presented as the difference from the default situation.

	Farrowing		Fattening		Slaughtering	
Variable	Cost price (Dfl. 119.7)	Farm income (Dfl. 61,568)	Cost price (Dfl. 189.5)	Farm income (Dfl. 36,524)	Cost price (Dfl. 48.2)	Income/fte (Dfl. 38,173)
Labour[1]	-4.37	0	-2.63	+814	-3.83	+705
Interest[1]	-3.20	+5,545	-3.78	+10,513	-0.73	+1597
Prices						
Gilts	-2.26	+7,012	0	0	0	0
Feed	-8.03	+27,585	-22.58	+136,130	0	0
Piglets	0	-75,049	-0.66	+134,722	0	0
Meat	+1.52	-5,918	0	-343,889	0	+154,687

[1] Default input values are presented in Appendix 3.II.

3.3.4 Sensitivity analysis chain: interstage relations

In Table 3.11, results are presented of several sensitivity analyses on values of input variables related to interstage relations. In the default situation, combination of the total chain production costs per pig and the chain revenue received at selling the pigmeat, yielded a negative net chain result of Dfl. 31.2 (Table 3.11). In Table 3.11 it is shown that in many cases changes within one stage of the chain do not affect performance and costs in other stages adversely. Moreover, in case adverse effects on costs or returns (Table 3.11) were found, the net result of the various stages could still be affected similarly as a result of counteracting transfer prices.

The big effects on fattening costs and chain revenues of the two breeding type alternatives (Table 3.11), resulted mainly from the smaller average carcass weight (Table 3.3). Compared with the results of the 'White' breed progeny, the so-called 'Meat' breed type improved the economic result of the farrowing and the slaughtering stage, but caused the fattening costs to be increased by Dfl. 2.27. In total the 'Meat' breed progeny yielded an improvement of the net chain result of Dfl. 0.97 compared with the 'White' breed progeny.

Changing from specialized farrowing and fattening operations to an integrated farrow-to-finish operation, both the farrowing and fattening stages incurred cost benefits while the slaughtering stage incurred a loss. This effect resulted from various causes. Firstly the combination of farrowing and fattening caused the scale of the operations to be reduced from 165 sows and 2000 fattening pigs on average present on specialized farms, to 107 sows and 715 fattening pigs on an integrated farrow-to-finish operation. As the supply and demand of feeder pigs were matched in the integrated operation, the biggest reduction in scale concerned the fattening stage. Although the smaller scales caused investments in e.g. housing to increase, other assets such as management and other 'fixed' labour and some general farm costs (Appendix 3.II) were shared. In total, this effect explained the reduction in feeder pig production costs. In contrast, the decrease in fattening costs resulted from the exclusion of feeder pig transportation costs and improved performance in terms of daily gain, feed conversion ratio and drug use (Table 3.5). For example, the annual number of fattening cycles increased by 0.05 while the feed conversion ratio decreased by 0.03. However, transportation efficiency and the percentage of fattened pigs without any pathological lesions decreased, causing an increase of slaughtering costs and a decrease in returns per carcass or parts sold (Table 3.11). In total, net chain result increased by Dfl. 3.53 per pig from farrowing to slaughtering.

Table 3.11 Results when input variables related to interstage relations are varied. Output values are presented as the difference from the default situation.

	Costs per animal (Dfl./head)			Total chain result (Dfl./head)		
Variable(s) and values	Feeder pig (119.7)	Hog (189.5)	Carcass: parts (48.2)	Costs (357.4)	Returns (326.2)	Net Result (-31.2)
Breed types (Stotfold trials)[1]						
- Meat type progeny	+0.06	-44.56	+2.99	-41.51	-85.13	-43.62
- White type progeny	+2.60	-46.83	+3.02	-41.21	-85.80	-44.59
Δ Meat - White types	-2.54	+2.27	-0.03	-0.30	+0.67	+0.97
Number of feeder pig suppliers[2]						
- 0: integrated farrow-to-finish	-1.48	-2.19	+0.11	-3.56	-0.03	+3.53
- 2 instead of 1 (default)	0	+3.77	+0.04	+3.81	-0.14	-3.95
Std. in growth rate hogs						
- low (-20%)	0	-0.16	-0.04	-0.20	+0.91	+1.11
- high (+20%)	0	+0.27	+0.11	+0.38	-0.77	-1.15
Number of hog deliveries						
- low (1)	0	-2.03	+0.20	-1.83	-1.02	+0.81
- high (3)	0	+0.68	-0.03	+0.65	+0.15	-0.50
Pens per fattening room						
- low (6)	0	+5.11	+0.02	+5.13	0	-5.13
- high (10)	0	-2.95	-0.01	-2.96	0	+2.96
Feed effects Auspig results[3]						
- high energy feeds	0	-21.17	+0.33	-20.84	+0.51	+21.35
- standard two-phase feeds	0	-13.81	+0.01	-13.80	+0.00	+13.80
Δ high energy - standard	0	-7.36	+0.32	-7.04	+0.51	+7.55

[1] The overall means (Stotfold trial results) considered for the White type progeny and the Meat type progeny input values are presented in Tables 3.1 and 3.2.

[2] see Table 3.5 and Appendix 3.II.

[3] The simulation results of AUSPIG used as input values considered for the standard two-phase feed alternative and the high energy feed alternative, are presented in Table 3.2.

In contrast, changing from one to two feeder pig suppliers caused productive performance to decrease, as was found by Elbers (1991) (Table 3.5). As a result, production costs both in the fattening and the slaughtering stage increased, while the chain revenue decreased by Dfl 0.14 (Table 3.11). An alternative which implied the transition from one to two feeder pig suppliers per fattening room included replacing the automated by a non-automated feeding system in the farrowing stage. Besides the economic effects of this alternative presented in Table 3.6, the smaller batches of feeder pigs available for weekly sale caused the transportation costs to rise with Dfl. 0.11 per fattened pig sold. These additional costs are not included in the effects presented in Table 3.11, in which the cause of the increase in feeder pig suppliers is not considered. Similar, but smaller effects on transportation costs of fattened pigs were found when the number of pens per fattening room was varied.

Decreasing the standard deviation in daily growth rate in the fattening stage resulted in cost benefits along the fattening and slaughtering stage of the chain. Total chain costs reduced by Dfl 0.20 per pig sold, while chain revenues increased by Dfl. 0.91. As a result, the net chain result increased by Dfl. 1.11. When the number of hog deliveries were decreased from two to one, there was a reverse effect on the performance of the slaughtering stage. While in the fattening stage production costs decreased by Dfl. 2.03, the production costs in the slaughtering stage increased by Dfl. 0.20. In general, the net chain result increased by Dfl. 0.81.

Using the simulation results of AUSPIG (Table 3.2), the high energy feeds improved economic performance of the fattening stage considerably compared with the standard diet. Economic benefits resulted mainly from improved efficiency increasing the number of fattening cycles by 10% per year and from lower manure costs (-22%) because of reduced manure production and lower levels of Phosphate-surpluses. Because of the higher average lean meat percentage of the carcasses, also the slaughtering stage incurred additional returns exceeding the extra costs. In total, the net chain result increased by Dfl. 7.55 per pig from fattening to slaughtering. The effects for the feed manufacturer were not considered however. Though the higher prices of the high energy feeds were considered, this may also hold for the raw material costs or feed production costs. Moreover, per farm the annual amount of feeds bought decreased by approximately 7%, implicating at least short term consequences for the efficiency of the use of fixed assets.

3.4 DISCUSSION

This paper described an economic chain simulation model in which cost price simulation was used to gain insight into - the distribution of - costs and benefits along the farrowing, fattening and slaughtering stages of the pork production-marketing chain. Transportation of animals between the stages was also taken into account. In practice, the total pork chain involves a larger number of stages. To gain insight into chain relations and reduce complexity, this limited number of stages in the model were considered appropriate. The approach as such, however, allows more stages to be included.

From the results it could be concluded that the integral chain production costs were made up mainly of fattening (53%) and farrowing costs (34%). Slaughtering and processing costs accounted for 13%. In the latter stage, lead-times are of course much shorter however. Feed costs were found to be a major cost component of the farm production costs and income, while meat and labour prices proved to have a major impact on the slaughtering and processing results. In general, changes in prices paid or received for animals proved to have a major effect on the returns to labour and management along the stages of the chain. However, because the raw material costs made up approximately 85% of the total cost price in the slaughtering stage, this held in particular for the slaughtering stage. Lorenz (1991) also emphasized the relatively high contribution of raw material costs to overall slaughtering costs per hog.

Also in the farm stages, farm income was influenced considerably by changes in feeder pig and/or meat prices. However, in the farrowing stage, also changes in litter size had a major effect, while in the fattening stage daily growth rate proved to be one of the most important technical input variables. With respect to the farrowing stage, Jalvingh et al. (1992) and Huirne et al. (1992) found comparable results. In calculating transportation costs per animal, the occupation rate of the truck was found to have the largest impact on transportation costs. Therefore, (inter)national regulations aimed at reducing truck stock densities or the number of farms animals come from in a truck and on a farm, may be expected to have a major impact regarding transportation costs.

Using a chain approach instead of analysis at the level of individual stages, has been shown useful in increasing insight into the effects of pig performance variables. This especially refers to revealing conflicting economic effects in stages downstream of the stage from which the effects originated. For example, in Table 3.11 it was shown that due to the assumed improved performance in the fattening stage and the sharing of some general farm costs, the decrease in economies of scale was more than outweighed as far as the farm stages were concerned. However, regarding transportation and slaughtering of pigs additional costs were incurred. Although in total, the net chain result was improved, two chain participants incurred the benefits were one suffered a loss. Similar effects were found in the comparison of the results of the two different breed types. Compared with the

White breed type, the performance of the Meat type progeny improved net chain result at the benefit of the farrowing and slaughtering stages but at the expense of the fattening stage. It is emphasized here that the examples presented in this paper are purely aimed at demonstrating the relevance of chain effects rather than implying to exactly represent real life practice. Results obtained are the outcome of assumptions and input changes made. When, for example, the performance improvements were ignored when integrating pig farrowing and fattening in one operation, the exclusion of the feeder pig transportation costs and the sharing of some general farm costs were no longer sufficient to make up for the decrease in scale economies in the fattening stage. In total however, still a net chain benefit of Dfl. 0.61 per pig was realised.

Moreover, in many cases changes within one stage of the chain did not affect performance and costs in other stages adversely. Besides, many alleged conflicts were undone or reversed by transfer pricing systems. The net chain benefit resulting from reducing the number of deliveries per fattening room from two to one, turned out to imply a reverse from a seemingly benefit (lower costs) into a net loss of the fattening stage, when the change in the returns per fattened pig (- Dfl. 2.36) were considered. In fact, this meant that the net chain benefit of Dfl. 0.81 per pig consisted of a net loss (Dfl. 0.33) for the fattening stage and a net profit (Dfl. 1.14) for the slaughtering stage. A deducted observation may be that some alternatives seem to evoke disproportionate effects on purchase and sales prices especially in the slaughtering stage. Although an in- or decrease in gross margin has to be reduced by in- or decreasing production costs, still it seems that the quality premiums and discounts included in the pricing systems alter the purchase price to a bigger extent than the sales price. Moreover, some alternatives were found to affect slaughtering and processing costs and benefits without having implications on the purchase price of fattened pigs. An example includes the percentage of pigs that is supplied without any pathological lesions (Tables 3.9 and 3.11, number of feeder pigs suppliers).

In short, as a result of transfer pricing systems, increased or decreased net chain results can be redistributed disproportionately. Since optimization of chain results will not be obtained as long as it means suboptimization of stage results, quantification of interstage relations and implementation of the results in transfer pricing systems may be important to prevent conflicts between stages. Therefore, research should be done to study ways to redistribute chain revenues along the stages of the chain, providing incentive structures that motivate the various agents along the chain to make decisions in a way that maximizes overall performance (King, 1992; Hovenier, 1993). Especially when chain products are differentiated according to criteria such as animal welfare and environmental issues, changing both the distribution of costs incurred in the stages along the chain and the revenue received from the final user, redistribution of final value may be crucial in controlling stage activities. Since prices influence incentives affecting economic decisions, they can be used to serve as appropriate signals to transmit consumer preferences for quality through all stages of the chain system. The pork chain simulation model described is also used in a forthcoming paper to analyze this kind of transfer pricing problems.

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Appendix 3.I Labour[1] and investment[2] requirements in the various stages of the pork chain

Stage of the chain	Unit	Default	Deviations from default			
Farrowing[3]	hours		non-automated feeding		piglets in nursery	
young replacement gilt	pig/year	2.8	+2.0			
Sow in:						
- mating area	pig/year	8.2	+2.0			
- pregnant sow area	pig/year	2.1	+2.0			
- farrowing area	pig/year	16.2	+4.3		-3.4	
litter piglets	litter/year	8.7	+1.8		+1.3	
boar	pig/year	6.0	+1.4			
'fixed' labour	sow/year	4.6				
investment	Dfl./sow	4989	-5%		+8.5%	
Fattening[4]	minutes		non-automated feeding		semi-automated	
- reoccupation with piglets	piglet	0.55				
- daily feeding	hog/year	56.4	+0.6		+0.3	
- health care						
.group treatment	hog	0.31				
.individual treatment	hog	2.88				
- control & climate	room/day	1.1				
- mucking out	pen/cycle	1.8				
- delivering hogs	hog	0.75				
- cleaning & disinfection	pen/cycle	40.2				
'fixed' labour per hog	hog/year	24				
investment hog place	Dfl./place	790	-9%		-8%	
Slaughtering[5]	minutes		PN[6]	LC	IL	SL
pig slaughtering	pig/year	8	+0.4	+1.5	+2	+2.5
pigs condemned at ante mortem visual inspection	pig/year	14				
further cutting of carcasses	pig/year	119				
'fixed' labour per pig	pig/year	21				
Investment						
- production of carcasses	Dfl./pig/year	47.5				
- production of cuts	Dfl./pig/year	60.6				

1 Based on Van der Schilden et al. (1992).

2 Based on a herd size of 165 sows or 2000 fattening pigs (2130 places) per farm, respectively.

3 The default values apply to automated feeding, half-slatted floors within sow areas, battery-systems for weaned piglets, and the all-in-all-out system for lactating sows and weaned piglets.

4 The default values apply to an automated feeding system, compartments with 8 pens suitable for 10 hogs each, 2 deliveries from each compartment, half-slatted floor pens and the all-in-all-out system.

5 Based on a slaughter capacity of 400 pigs per hour and cutting more than half of all carcasses produced.

6 PN: Pneumonia, LC: Lungs impossible to Classify, IL: Inflammation of the Leg, SL: Skin Lesions

Appendix 3.II Default values of economic input variables of the farrowing and the fattening stage

Economic input variable	Unit	Farm	Farrowing	Fattening	Slaughtering
general costs	Dfl./farm	7834			
	Dfl./place[1]		25	3.5	
health care[2]	Dfl./sow		68		
	Dfl./gilt		20-32		
	Dfl./boar		10		
heating, water &	Dfl./sow or hog		100	5	
electricity	Dfl./gilt		6.5-13		
	Dfl./boar		24		
membership contribution	Dfl./gilt		0.26		
	Dfl./sow or boar		1.83		
	Dfl./hog			0.26	
disposal of manure	Dfl./m^3		17.50	15	
artificial insemination	Dfl./sow/cycle		20		
labour	Dfl./hour	32.5			32.5
interest	% av. investment	9.3			9.3
depreciation rates	% investment				
- investment/pig place			8	7.3	
- buildings					4
- heating machinery					10
- slaughter machinery					15
- PC's & office equipm.					20
maintenance costs	% investment		1	1	

1 Based on an average family farm with a herd size of 165 sows and 2000 hogs respectively, and an automated feeding system.

2 Health care costs per hog depend on the number of drug-free fattening rounds (see Table 3.5 and the section on interstage relations).

Chapter 4

COSTS, BENEFITS AND TRANSFER PRICES IN DIFFERENTIATED PRODUCTION-MARKETING CHAINS FOR FRESH PIGMEAT[1]

ABSTRACT

An economic pork chain simulation model was used to study the effects of various differentiated pork chain concepts on technical and economic performance of both the chain as a whole and the individual stages. The differentiation aspects concerned food safety and hygiene, carcass and meat quality, and animal welfare. Compared with standard pork production, two differentiated pork concepts derived additional chain benefits varying from Dfl. 0.7 to Dfl. 50.2 per pig sold, depending on market conditions. One concept incurred an additional loss of about Dfl. 11.9 per pig sold. Benefits and losses were redistributed among the stages of the chain disproportionately, however. Therefore, a conceptual framework was designed and used to quantify the effects of several transfer pricing systems. Various so-called 'cost-plus' based transfer pricing systems proved to have a considerable, though smaller, impact on the transfer premiums calculated than did the varying market conditions. However, all systems described resulted in consistently shared extra profits or losses. Although generally accepted criteria for choosing a 'fair' transfer pricing system seem to be lacking, the effects of the groups of transfer mechanisms described were found to be rather stable. A profound analysis of expected market share and regular updating of transfer prices were found to be of crucial importance.

4.1 INTRODUCTION

There is a growing tendency for single enterprises to intensify vertical cooperation within agricultural production-marketing chains. Reasons for this include both specific characteristics of agricultural food chains and changes in market conditions (Den Ouden et al., 1996a). Nowadays, increasingly diverse consumers show a growing interest in product quality as well as in the manner of production and distribution, concerning issues such as food safety, quality and convenience, animal welfare and environmental pollution (Anonymous, 1992; Barkema, 1993; Miller, 1994). This creates opportunities for selecting market segments to which more value can be offered through product differentiation. Simultaneously, those changed preferences have to be passed on to farm

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[1] paper by Den Ouden, M., Huirne, R.B.M. and Dijkhuizen, A.A. submitted for publication to *Agricultural Economics*.

stages especially. In Dutch pork industry, differentiated chains were developed, which put special demands (and costs) on the production process to guarantee final products that meet these specific consumer demands.

Particularly in the case of product differentiation it is desired to gain insight into the way costs and benefits in the various stages of the chain are influenced and distributed. These insights may help to develop effective - transfer pricing - instruments. Since prices are considered effective incentives in affecting economic decisions, they can be used to serve as appropriate signals to pass on consumer preferences to all stages of the vertical system. For this paper an economic pork chain simulation model (Den Ouden et al., 1996b) was used to quantify the effects of three differentiated pork chain concepts. Compared with standard pork production, the differentiated pork concepts were characterized according to specific demands on origin of animals, hygiene and drug use, and according to special feeds, housing and handling systems in order to improve either carcass quality or animal welfare or both. Effects on technical performance, additional costs and chain benefits were quantified. Although two differentiated pork concepts derived additional benefits for the chain as a whole, results showed an unbalanced distribution of extra costs and benefits over the individual stages. The effects of varying market conditions on chain profitability and distribution of profits and losses were demonstrated as well. Furthermore, a conceptual framework was presented and used to study and quantify the effects of several transfer pricing systems.

4.2 MATERIAL AND METHODS

4.2.1 Pork chain simulation model

The purpose of the pork chain simulation model is basically to simulate technical and economic performance of individual stages and pork production-marketing chains as a whole. Special emphasis is put on the economics of interstage relations and product differentiation. Economic figures are presented per animal or per carcass sold where costs incurred are divided into labour costs, interest, depreciation, raw material costs and various costs.

Input variables of the model involve economic items such as feed prices, interest rates and depreciation times and technical items such as farm lay-out, culling and reproduction policies, assumed daily gain etc. The farm lay-out, including housing and feeding facilities, is related to the labour required for handling the animals in the farm stages. In the default situation, feeding is assumed to be either a semi-automated or a non-automated activity. Based on the input values, technical and economic output is calculated. An important example in the farm stages concerns the farm scale, which represents the number of animals one full-time equivalent can handle. The farm scale is related to the efficiency of fixed assets such as housing facilities. Moreover, together with output on, for example, the number of production cycles realized per year, it determines how many pigs can be sold per year. In turn, the number and live weight of pigs sold per time unit, influence transportation efficiency and costs. Other examples of interstage relations are embedded in the way fattening input, such as desired final live weight, standard deviation in daily gain and delivering strategy, influence the performance of both pig fattening and slaughtering. These parameters affect the distribution of carcasses over quality classes in the slaughterhouse. Based on demand specifications, the carcass quality classes are related to options of processing the carcass and therefore to processing costs and the potential value of a carcass. A comprehensive description of the model structure and behaviour has been presented in an article by Den Ouden et al. (1996b).

4.2.2 Differentiated chain concepts

Within the Netherlands various pig chain concepts were developed (Den Ouden et al., 1996a). The three examples described in this paper are based on concepts practised in the Dutch market. The first and most common concept in pig production is called 'Integrated Quality Control' (IQC). It was designed to provide consumers with guarantees on hygiene, food safety and origin of the pork (Anonymous, 1994; Tazelaar and Gerats, 1995). Key issues involve the recording of information and its exchange between the stages of the pig chain. Moreover, only a limited number of medicines are approved for use in only a limited period of the production cycle. It has been practised since 1992 and includes pig farrowing (from 1993), fattening and slaughtering. Covering already about 45% of the pigs produced in the Netherlands in 1995, it is growing rapidly to the goal of becoming the national standard. As such it will also be the basis for consumer labelled pork products to be developed. Without referring to the real brand name, one of the examples of consumer labelled pork presented here is called IQC^{+}. It concerns pig fattening and processing only and involves stronger demands on drug use, special feeds aimed at improving carcass and meat quality, and some housing modifications regarding pig welfare. The last example of consumer labelled pork that is described is based on the 'outdoor' pig concept. It pursues an improvement of the pigs' welfare through modifications in housing, handling and feeding of pigs (Anonymous, 1991). This concept involves pig farrowing, fattening and slaughterhouses.

Table 4.1 Major technical and economic input values of the farrowing, fattening and slaughtering stages of the standard (default), the IQC, the IQC+ and the 'outdoors' pig chain concepts.

Variable	Default	IQC	IQC+	Outdoors
Farrowing stage				
group housing non-lactating sows	No	-	-	Yes
concrete floor space nursery (m^2)	0	-	-	+4
total floor space nursery (m^2)	3.75	-	-	+2.75
outdoor space (m^2)	0	-	-	+10
straw supplied (kg/sow/day)	0	-	-	+0.3-1
concentrate-roughage ratio	5:0	-	-	5:1
pre-weaning mortality rate (%)	13.2	-	-	+2.8
weaning age piglets (days)	28	-	-	+14
special record keeping requirements	No	Yes	Yes	Yes
control chain concept requirements	No	Yes	Yes	Yes
membership-fee (Dfl./feeder pig)	0	-	-	+2.80
premium price (Dfl./feeder pig)	0	+1.0	+1.0	+23.38
Fattening				
concrete:total floor space (m^2/pig)	0.32:0.74	-	0.3:1.0	0.625:0.95
outdoor space (m^2/pig)	0	-	-	+0.625
straw supplied (kg/pig/day)	0	-	-	+0.1
concentrates-roughage ratio	10:0	-	-	10:1
average daily gain (grams/day)	719	-	+10	-30
feed conversion ratio	model[1]	-	-0.06	+0.15
special record keeping requirements	No	Yes	Yes	Yes
control chain concept requirements	No	Yes	Yes	Yes
price finishing feed (Dfl./100 kg)	44.7	-	+20%	-
membership-fee (Dfl./pig)	0	-	-	+2.80
premium price (Dfl.)	0	+4.0/pig	+0.38/kg	+0.91/kg
Slaughtering				
price of ear tags (cents)	3.83	+1.55	+1.55	-
% pigs condemned ante mortem	1.50	-0.2	-0.35	-
carcass weight (kg)	83	-	+2	-
% of pigs without lesions	79	-	-5	-
% best body composition-quality	14	+2	+9	-
control chain concept requirements	No	Yes	Yes	-
Premium price (Dfl./kg)	-	+.25/kg	+1.1/kg	-

As there were no data available on the slaughtering stage, this stage has not been considered in the analysis of the outdoor concept. In Table 4.1 the specific production conditions of the three chain concepts are presented as deviations from the input values of the default pig chain. All data refer to the 1992/1993 situation. Data were gathered from production manuals (Anonymous, 1991), literature (De Kleijn et al., 1991; Bens, 1994) and commercial databases. Although they relate(d) to real-life chain concepts, they were simplified for illustrative reasons and reasons of simplicity and confidentiality.

The additional IQC record keeping tasks are assumed to take about 15-30 minutes extra per week. Moreover, two times a year, each farm is submitted to a routine audit, which is assumed to take about half a day. Within the IQC concept, a premium was paid of Dfl. 1.0 per feeder pig and Dfl. 4.0 per fattened pig sold (Table 4.1). With respect to the IQC^+ concept, it can be seen in Table 4.1 that its requirements include those of IQC, extended with larger floor space requirements and other - more expensive - feed in the fattening stage. As a result, average daily gain is assumed to increase by 10 grams a day, while the feed conversion ratio is reduced by 0.06. Compared with IQC, no changes were assumed in the farrowing stage. Per pig sold a premium of Dfl. 0.38 per kilogram of carcass weight was paid (Table 4.1). The fattening pig premiums were paid for all animals supplied regardless of whether or not they met all concept specifications. Only boars and pigs that were condemned in ante mortem inspection at the slaughterhouse, were not allocated a premium price. This meant that also for pigs that, for example, had been given medicines after the production period allowed, the bonus was received. Although the meat of those pigs could no longer be sold according to the concept specifications, this was done to assure the supply of reliable information.

The outdoor concept involves additional requirements concerning more indoor and outdoor space, supply of straw and roughage, group housing of non-lactating sows and an increased weaning age of piglets. In the Netherlands, technical performance of 'outdoor' herds has been found to be somewhat lower than average (De Kleijn et al., 1991; Bens, 1994). For example, feed conversion ratio and daily gain are believed to be 0.15 higher and 30 grams per day lower respectively than average. Higher fluctuating climatic conditions and the higher rate of exercise due to more - outdoor - space are often mentioned as possible explanations (Bens, 1994). On the other hand, the use of straw, for example, reduces the need for heating facilities in some areas of the barns. Besides the premiums received for these animals when sold, also a membership-fee was paid per animal to the International Association of Outdoor Pig Producers (Anonymous, 1991) (Table 4.1).

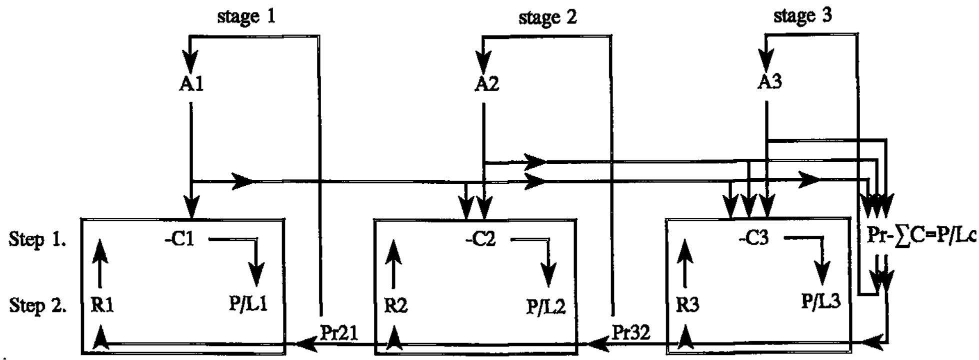
To be able to recognize and to separate pigs from various concepts, and pigs that do not meet the concept specifications, differently coloured ear tags were used (Table 4.1). Besides, several other precautions and activities were necessary to keep the carcasses and meat from various concept sources separated during slaughtering and processing and to mark the switch to other concepts. For example, small numbers of slaughter-hooks were deliberately left open to visually mark the shift to slaughtering pigs of another concept. Also additional tasks were required in processing the information supplied, visiting the suppliers for routine audits twice a year and the audit of the slaughterhouse itself each 6 months.

IQC and IQC^+ pigs were found to have a somewhat higher carcass quality compared with the default situation. The percentage of carcasses in the best body composition class increased from 14% (default) to 16% and 23% for IQC and IQC^+ respectively. Regarding IQC in particular, this may have resulted from the early adopters possibly consisting of relatively better-performing farms. The increased attention for the health status of pigs might have contributed to a lower percentage of pigs condemned at ante mortem visual inspection. On the other hand, factors, such as more freedom of movement, may have caused a somewhat higher percentage of carcasses with pathological lesions (IQC^+). Of course, the assumptions made with respect to input values will determine the output. However, the big advantage of using the simulation model is that it is flexible enough to allow the user to adapt input values to production and market conditions throughout the world.

4.2.3 Conceptual redistribution framework

In accordance with transfer pricing theory, effective payment systems should (1) lead to economic decisions that positively affect chain performance, and (2) give the different participants the feeling that they are fairly rewarded for their contribution to the chain result (Eccles, 1985). Schematic conceptual frameworks for analysis of the distribution of profit or loss in general and transfer pricing in particular are given in Figures 4.1 and 4.2 respectively.

Figure 4.1 represents a hypothetical chain consisting of three successive stages. Costs, returns and profit or loss at stage i are denoted by C_i, R_i, and P/L_i respectively. Activities performed at stage i, denoted A_i, may influence both costs incurred in that stage and the performance of subsequent stages. The combined activities performed determine the bundle of characteristics of the product finally sold to the end buyer. In this way the price the final buyer is willing to pay will be affected as well. In analyzing the distribution of profit or loss of (differentiated) products, first (step 1) total (additional) costs ($\sum_i C_i$) and (extra) final buyer price (Pr) are combined to yield the total (additional) net chain profit or loss (P/L_c). Subsequently (step 2), it is analyzed how Pr is redistributed or passed on to the individual preceding stages, via the transfer prices $Pr_{i+1,i}$, i.e. the prices transferred from stage 'i+1' to the preceding stage 'i'. The transfer prices determine the level of returns per stage (R_i) and the distribution of P/L_c over profit or loss of the individual stages involved (P/L_i).



Ai	= Activities performed at stage i
Ci	= Costs incurred at stage i (excl. products received from stage i-1)
Pr	= Final buyer Price received at the end of the chain
P/Lc	= Profit/Loss, or net result, of the chain as a whole
Pri+1,i	= transfer Price paid at stage i+1 for products received from stage i
Ri	= Returns at stage i
P/Li	= Profit/loss, or net result, at stage i

Figure 4.1 Conceptual framework for analysis of distribution of profit or loss and transfer prices in general

In analysing transfer prices one can take a retrospective (positive) approach or a prospective (normative) approach. In the first case it is analysed what the level of the transfer prices and the distribution of profit or loss over the individual stages currently is or has been in the past. In the latter case, one analyses the effects of potential (future) transfer prices or transfer pricing systems. Transfer prices are affected by various factors. Market conditions including the final buyer price and the absolute market demand or market volume, make up the total (extra) chain value or returns determining net chain profit or loss. Of course the bigger the (extra) value the more is available for passing on to preceding stages. The way of redistribution, i.e. the transfer pricing system, comprises two aspects. First one has to decide on the subject of payment, i.e. on the definition of product- or production-specifications and the unit of payment, i.e. on whether the transfer price is related to a flock of animals, an individual animal or carcass, or to specific carcass- or product(ion)-attributes. The principle of the transfer pricing system involves the way of redistribution itself, i.e. choosing for absolute or relative contributions of stages to chain value or costs and, for example, the definition of the cost-base (total costs, factor costs etc.). A schematic framework is presented in Figure 4.2.

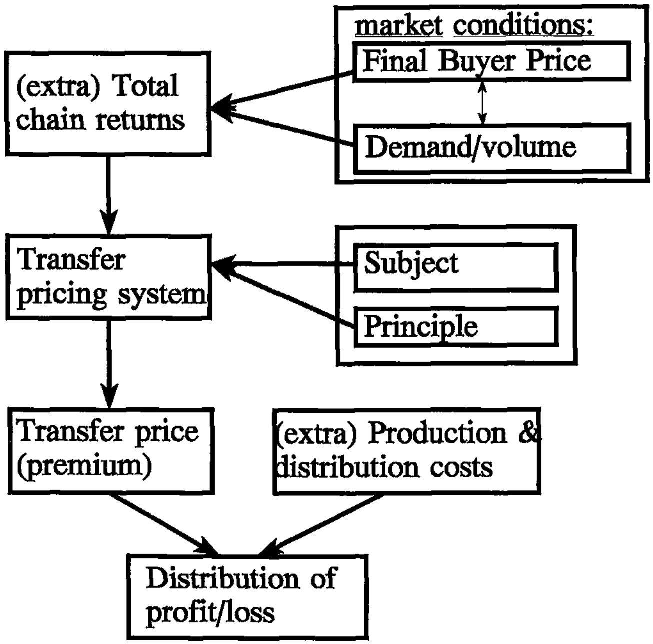


Figure 4.2 Conceptual framework of factors involved in transfer pricing analysis in particular.

Regarding differentiated products, transfer prices usually include premiums or discounts paid in addition to regular market prices. This additive approach was also followed in the normative calculation of the transfer prices of the differentiated chain concepts described in this paper. General assumptions in the normative calculation of the transfer prices included that 1) no opposite changes in extra net results occurred among chain participants, 2) premiums are adjusted for potential benefits in the form of carcass quality premiums, and 3) no discounts instead of premiums are calculated if the extra net chain result is positive. Furthermore additional costs per stage are compensated for and the remaining extra net chain result is divided among the chain participants according to a certain transfer pricing system. In general, this type of transfer pricing systems based on compensation of (additional) costs plus a part of the net chain result are denoted as the so-called 'cost-plus' transfer pricing systems. Using cost-plus based transfer keys may be interpreted as a compromise for prices not (yet) being available in the market place or imperfect interstage market prices.

Cost-plus based transfer systems can be based on either the absolute or the relative contribution of each stage to certain chain costs. In case of relative cost analysis, additional costs are compared with a predefined default situation. For each of the chain concepts, IQC, IQC$^+$ and outdoor, similar transfer keys were used. Types of costs considered were total production and distribution costs, total factor costs - being the cost of labour and capital employed -, and total costs of the presumed own fixed assets i.e. labour and 35% of total capital employed. The latter system is used in the Netherlands for distributing profit or loss in weekly-published feeder pig and fattening pig prices. With respect to IQC$^+$ there were no changes in the farrowing stage compared with the IQC concept (Table 4.1). Therefore in calculating premiums for the IQC$^+$ concept, an extra group of transfer keys was used in which the feeder pig premiums were kept equal to the corresponding feeder pig premiums calculated in the IQC concept.

4.3 RESULTS

4.3.1 Differentiated pork chain concepts

In Table 4.2, major technical and economic results of the different chain concepts are presented. Regarding IQC, IQC$^+$ and Outdoor, results are presented as the difference compared with the results of the default chain.

With respect to the farm stages, major effects on overall efficiency were found in the outdoor chain. Besides considerably higher labour requirements, especially caused by supplying roughage and straw, overall efficiency was further reduced by the decrease in the annual number of production cycles. Primary causes of the latter included the increased weaning age of piglets in the farrowing stage and the lower growth rate of fattening pigs. As a result, the farm scale dropped from 127 sows and 1466 fattening pigs on average present in the default situation to 93 sows and 767 fattening pigs respectively. Scale diseconomies were found in labour costs, some general farm costs, and housing costs in particular. In the farrowing stage feed costs per sow per year decreased, however. This resulted mainly from the lower amount of expensive piglet feed as a result of a longer lactation period. In contrast, a lower feed conversion ratio and the extra roughage costs resulted in an increase of feed costs per fattened pig sold. Moreover, although the heating costs declined, total various costs increased. This was mainly due to the cost of straw, the membership-fee paid to the association of outdoor pig producers, increased manure costs and some scale diseconomies in overall farm costs.

Table 4.2 Major technical and economic results of the various pork chain concepts: default, IQC, IQC+ and outdoor. As no data were available on the slaughtering stage of the outdoor chain, results of this stage are not presented.

Technical results	Default	IQC	IQC+	Outdoor
Farrowing stage				
labour (hours) per sow	18.4	+0.2	+0.2	+6.8
production cycles pspy[1]	2.29	-	-	-0.19
feeder pigs sold pspy	21.1	-	-	-2.38
Fattening stage				
labour (hours)/pig sold	0.5	+0.01	+0.02	+0.52
feed conversion rate	2.80	-	-0.06	+0.15
production cycles/year	2.94	-	-0.03	-0.12
Slaughtering stage				
% pigs premium buy	-	0.97	0.99	-
% carcasses premium sales	-	0.15	0.25	-

Economic results	Default	IQC	IQC+	Outdoor
Farrowing stage				
labour costs/pspy	599.4	+6.3	+6.3	+222.1
housing costs/pspy	717.7	+0.4	+0.4	+138.4
feed costs/pspy	834.6	-	-	-53.6
other costs/pspy	503.5	+0.7	+0.7	+141.9
Total costs/pfps[1]	125.8	+0.3	+0.3	+39.95
Revenue/pfps	107.6	+1.0	+1.0	+23.4
Net result/pfps	-18.2	+0.7	+0.7	-16.6
Cash flow/pfps[2]	12.0	+0.7	+0.7	-7.0
Annual farm income[3]	48,406	+2,032	+2,032	-15,320
Fattening stage				
labour costs/pps[1]	17.0	+0.3	+0.6	+16.9
housing costs/pps	34.4	+0.05	+5.6	+8.6
feed costs/pps	111.1	-	+14.3	+8.2
transport fp/pps	2.4	-	-	+0.2
other costs/pps	27.1	+0.07	+0.48	+10.6
Total costs/pps	192.0	+0.4	+20.9	+44.5
total costs + feeder pig	301.9	+1.4	+21.9	+68.4
Returns/pps	282.8	+5.2	+43.7	+72.5
Net result/pps	-19.2	+3.8	+21.7	+4.2
Cash flow/pps[2]	12.9	+3.9	+26.4	+11.9
Annual farm income[3]	34,892	+17,517	+100,237	+35,403
Slaughtering				
transportation/pcs	3.7	-	+0.05	
Total costs/pcs[1]	48.2	+0.8	+1.97	
total costs + pig	331.0	+6.0	+45.6	
Returns/pcs	326.2	+2.2	+31.5	
Net result/pcs	-4.8	-3.8	-14.1	
Cash flow/pcs[2]	0.7	-3.8	-12.6	
Annual income[3]/f.t.e[1]	38,059	-8,801	-35,690	
Chain				
Total costs/pig	366.0	+1.5	+23.2	+84.4
Returns per pig	326.2	+2.2	+31.5	+72.5
Net result/pig[4]	-39.9	+0.7	+8.3	-11.9

1 pspy = per sow per year, pfps = per feeder pig sold, fp = feeder pig, pps = per pig sold, pcs = per carcass/cuts sold, f.t.e. = full time equivalent

2 Cash flow = net result + depreciation + (calculated - paid) interest

3 Annual income = (net result + labour + (calculated-paid) interest) * animals sold/year/f.t.e.

4 Chain net result + loss rate fattened pigs (2.1%) * feeder pig price = sum net results per stage

Because outdoor space was only partly covered by a roof, rain water caused the total manure-water volume to increase resulting in higher manure removal costs. Smaller batches of feeder pigs caused an increase of feeder pig transportation costs incurred in the fattening stage.

With respect to the IQC and the IQC^+ concepts only minor effects on labour use and costs were found, as were the scale diseconomies in housing and sharing other general farm facilities. Although a higher growth rate was assumed in IQC^+, the annual number or production cycles realized decreased by 0.03 (Table 4.2) as a result of the higher final live weight desired (Table 4.1). Notwithstanding the higher nitrogen level of the IQC^+ finishing feed, manure costs per fattened pig slightly declined due to the improved feed conversion ratio. In total, both IQC and IQC^+ incurred higher slaughtering and processing costs. However, the lower percentage of pigs condemned at ante mortem inspection was responsible for an overall reduction of the slaughtering costs.

Regarding IQC, about 80% of the total extra costs were related to the intensified relations with suppliers, including the twice-yearly IQC chain audits of the farmer-suppliers and the slaughterhouse itself, and the higher degree of further processing of carcasses. The major part of the remaining costs consists of extra paperwork and separation and switching costs during slaughtering. With respect to IQC^+, about 50% of the total extra costs were related to intensified supplier relations and further processing. Because IQC^+ is a smaller scale concept, the accounted additional tasks for information processing, quality control, separation and switching amounted to over 25% of total extra costs per pig slaughtered. Moreover, more than 20% of the extra costs were incurred as additional distribution-marketing costs.

In total, both the IQC and the IQC^+ concept incurred an increase in net chain profit of Dfl. 0.7 and Dfl. 8.3 per pig respectively (Table 4.2), while the outdoor concept incurred a decreasing net farrow-to-finish result. With respect to the latter, the fattening stage, however, improved its net result by Dfl. 4.2 per pig sold. Also in the IQC and IQC^+ chains the extra net chain result seemed to be redistributed reversely, resulting in a decrease in net slaughtering result while the farrowing and fattening stages reaped the benefits. As shown in Table 4.2, the slaughtering stage paid premiums to about 97% and 99% of all IQC and IQC^+ pigs supplied respectively. On the other hand, demand conditions were supposed such that only a part of the carcasses could be sold at a premium value, assumed percentages were 15% and 25% respectively. As a result, Dfl. 5.2 and Dfl. 43.65 were paid extra per average IQC and IQC^+ pig, while extra values of only Dfl. 2.2 and Dfl. 31.5 were received per (processed) carcass sold. Besides the concept premiums of Dfl. 3.9 and Dfl. 31.7 per average IQC and IQC^+ pig, also higher prices were paid for higher carcass quality (see Table 4.1).

4.3.2 Effects of market prices and volumes on the distribution of profit or loss

As shown in Table 4.2, chain profit or loss can be redistributed conversely among the chain participants. Besides the premiums paid or received, also variation in market prices may cause this effect. In Figure 4.3, the average 1992 and 1993 bulk market prices of feeder pigs, fattened pigs and (processed) carcasses are presented. Combined with the average prices of pig feed and replacement gilts in the same period, the distribution of cash flow over the stages involved could be simulated (Figure 4.3). In general, prices were at their highest level in the first semester of each year, while the average price levels of 1992 clearly exceeded those of 1993. As a result, simulated cash flows, although positive for all stages in 1992, were negative in 1993. Moreover, within each year the distribution of the simulated cash flow varied considerably among the stages involved.

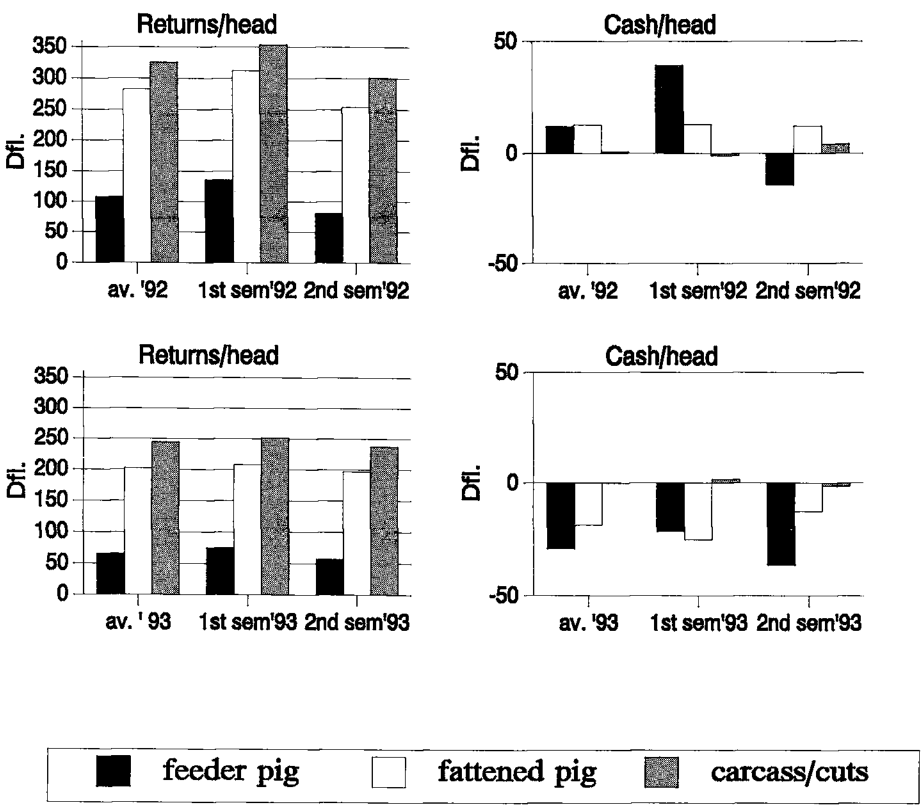


Figure 4.3 Distribution of returns and cash flow over the farrowing, fattening and slaughtering stages, using prices of 1992 (top) and 1993 (bottom).

Where the farrowing stage got the biggest part of the chain benefit in the first semester of 1992, it was the only stage which incurred a cash loss in the second semester of 1992, and it incurred the biggest loss in the second semester of 1993.

In Table 4.3 the effects of market volumes on the net slaughtering and chain result are further illustrated. Obviously, if the market volumes of IQC and IQC$^+$ raised above the assumed 15% and 25%, more carcasses could be sold at a higher value. As a result, the premiums received per average (processed) carcass sold and the extra net results increased.

Table 4.3 The effect of market risks (selling alternatives) and various buying alternatives on the premiums and total prices paid and received per average pig, and the net slaughter and chain results (Dfl./head).

	% Pigs rewarded		Premium (Dfl./head)		Total price (Dfl./head)	
Alternatives[1]	IQC	IQC$^+$	IQC	IQC$^+$	IQC	IQC$^+$
Buying						
B_I	97	99	3.90	31.71	287.99	326.42
B_{II}	90	90	3.57	29.57	287.66	324.28
B_{III}	65	65	2.57	20.72	286.67	315.43
Selling						
S_I	15	25	2.22	31.51	328.38	357.67
S_{II}	65	65	9.57	61.81	334.54	386.78
S_{III}	90	80	14.16	74.82	338.90	399.56
			Δ Net result slaughter[2]		Δ Net result chain[2]	
Combination			IQC	IQC$^+$	IQC	IQC$^+$
B_I + S_I			-3.8	-14.1	+0.7	+8.3
B_{II} + S_{II}			+2.7	+17.1	+6.8	+37.4
B_{III} + S_{III}			+8.1	+38.8	+11.2	+50.2

[1] B_I : all pigs supplied except boars and pigs condemned at visual inspection
B_{II} : B_I without pigs that fail the concept guarantees
B_{III} : B_{II} without pigs that fail certain quality specifications
S_I : assumed customer demand
S_{II} : all carcasses that meet the quality specifications
S_{III} : all carcasses supplied according to the concept guarantee, except those with severe pathological lesions or of (too) poor quality

[2] Results represent the difference in Dfl./head compared with the results of the default chain concept.

At maximum, 90% and 80% of all IQC and IQC$^+$ pigs supplied respectively were assumed to be sold at the higher quality-concept value, representing all pigs that were supplied according to the concept guarantees, except pigs with severe pathological lesions or (too) poor quality (S_{III} Table 4.3). Based on customer demand specifications, additional quality specifications were supposed to be defined in terms of specified ranges of carcass weight, lean meat percentage, body composition and potential other carcass or meat quality parameters. Assuming these specifications, the saleable volume was reduced further (S_{II} Table 4.3).

4.3.3 Effects of transfer pricing systems on premiums and distribution of benefits

Besides additional marketing efforts to increase market shares or volumes, net slaughtering results could also be increased by further restricting the conditions at which premiums are paid (buying alternatives in Table 4.3). Of course, the latter alternatives will effect the net fattening result reversely. Definition of the subject of transfer pricing in terms of specifications of animals or carcasses which are rewarded or discounted, forms part of the total transfer pricing system (Figure 4.2). Combining the most favourable market alternative S_{III} with B_{III} (Table 4.3), the extra net IQC and IQC$^+$ result would increase by Dfl. 8.1 and Dfl. 38.8 respectively for the slaughtering stage and Dfl. 11.2 and Dfl. 50.2 respectively for the chain as a whole (Table 4.3). These results, however, need yet to be adjusted for potential additional costs as a result of, for example, further processing needs.

Table 4.4 presents the effects of various principles of transfer pricing (Figure 4.2) including several cost-plus based transfer pricing systems. Effects are shown on the premiums paid for intermediated products ($Pr_{i,i-1}$ Figure 4.1) and the resulting distribution of the extra net chain result (P/L_i Figure 4.1) of IQC, IQC$^+$ and 'Outdoor'. In case of IQC and IQC$^+$, results are shown for two possible market conditions (Table 4.3). Transfer pricing keys referred to either absolute or relative costs, the latter denoted as 'Δ' (Table 4.4). The specific group of transfer pricing systems used for the IQC$^+$ concept in which the feeder pig premiums were kept equal to those calculated for the IQC concept, was denoted as group (B).

It can be seen in Table 4.4 that all transfer pricing systems resulted in a consistent redistribution of the extra net chain result. Premiums calculated varied from Dfl. 0 tot Dfl. 44.3 depending on the chain concept considered, transfer pricing system and market volume assumed. Compared with the default chain concept, additional net returns changed accordingly. When evaluating the effects per chain concept, the market conditions proved to have a relatively bigger and more varying impact on both the total amount and the distribution of profit or loss than the transfer pricing systems (Table 4.4).

Table 4.4 The effects of various transfer pricing mechanisms on the premiums paid and the distribution of the additional net result of IQC, IQC+ and Outdoor compared with the default situation. Regarding IQC and IQC+, the results are presented for two selling alternatives (Table 4.3). The results of the basic situation are shown *in italics*.

		Sell alternative I									Sell alternative II				
		%			Premium		Δ Net Result			Premium		Δ Net Result		
Chain	Transfer system[1]	S[1]	F[1]	Sl[1]	S	F	S	F	Sl	S	F	S	F	Sl
IQC	-	*100*	*574*	*-574*	*1.0*	*4.0*	*+0.7*	*+3.8*	*-3.8*	*1.0*	*4.0*	*+0.7*	*+3.8*	*+2.4*
	TC	34	53	13	0.6	0.02	+0.2	+0.3	+0.1	2.7	5.5	+2.3	+3.5	+0.9
	TFC	43	35	22	0.6	0	+0.3	+0.3	+0.1	3.3	4.9	+2.9	+2.3	+1.5
	L35C	44	32	24	0.6	0	+0.3	+0.2	+0.1	3.3	4.8	+3.0	+2.2	+1.6
	ΔTC	22	28	50	0.5	0	+0.1	+0.4	+0.1	1.8	2.9	+1.5	+1.9	+3.4
	ΔTFC	24	28	48	0.5	0	+0.2	+0.4	+0.1	2.0	3.1	+1.6	+1.9	+3.2
	ΔL35c	24	27	49	0.5	0	+0.2	+0.4	+0.1	2.0	3.1	+1.6	+1.8	+3.3
IQC+	-	*8*	*262*	*-170*	*1.0*	*31.7*	*+0.7*	*+21.7*	*-14.1*	*1.0*	*31.7*	*+0.7*	*+21.7*	*+15.0*
	TC	32	55	13	3.0	16.8	+2.7	+4.5	+1.1	12.4	42.5	+12.0	+20.3	+4.8
	TFC	42	36	22	3.8	16.1	+3.4	+3.0	+1.8	15.9	39.2	+15.6	+13.4	+8.1
	L35C	43	33	24	3.9	15.9	+3.5	+2.7	+1.9	16.2	38.4	+15.9	+12.3	+8.8
	ΔTC	2	90	8	0.5	17.1	+0.1	+7.4	+0.7	0.9	44.2	+0.6	+33.6	+3.2
	ΔTFC	7	66	27	0.9	15.6	+0.6	+5.5	+2.2	2.9	37.2	+2.6	+24.7	+10.0
	ΔL35c	8	59	33	1.0	15.1	+0.7	+4.8	+2.7	3.5	34.9	+3.2	+21.8	+12.3
(B)	TC	IQC	81	19	0.6	16.3	+0.2	+6.5	+1.5	2.7	40.6	+2.3	+28.3	+6.7
	TFC		63	37	0.6	14.8	+0.3	+5.0	+3.0	3.3	34.3	+2.9	+21.5	+12.9
	L35C		58	42	0.6	14.5	+0.3	+4.7	+3.3	3.3	32.9	+3.0	+20.1	+14.3
	ΔTC		91	9	0.5	17.1	+0.1	+7.4	+0.7	1.8	44.3	+1.5	+32.7	+3.1
	ΔTFC		71	29	0.5	15.5	+0.2	+5.8	+2.3	2.0	36.9	+1.6	+25.4	+10.3
	ΔL35c		64	36	0.5	14.9	+0.2	+5.2	+2.9	2.0	34.3	+1.6	+22.8	+12.9
Outdoor	-	*134*	*-34*	-	*23.4*	*0.91*	*-16.6*	*+4.2*	-					
	TC	41	59	-	34.7	-	-5.2	-7.4	-					
	TFC	53	47	-	33.2	-	-6.7	-5.9	-					
	L35C	54	46	-	33.1	-	-6.9	-5.7	-					
	ΔTC	47	53	-	34.0	-	-6.0	-6.7	-					
	ΔTFC	49	51	-	33.8	-	-6.2	-6.5	-					
	ΔL35c	49	51	-	33.8	-	-6.2	-6.5	-					

[1] TC = Total Costs, TFC = Total Factor Costs, L35C = labour costs + interest on 35% of capital employed, ΔTC = Extra total costs compared with total costs default, ΔTFC = Extra factor costs compared with default, ΔL35c = Extra labour & interest (35% CE) compared with default, S = Sow stage, F = Fattening stage, Sl = Slaughtering stage

As a result of the general assumptions made, reverse changes did no longer occur in net results of chain participants. For example, where in the basic situation, the slaughtering stage incurred an extra loss of 170% of the total extra IQC^+ net chain profit assumed under selling alternative I (in italics in Table 4.4), it now incurred a net extra benefit varying from 8% to about 40% depending on the transfer pricing system used (Table 4.4). With respect to IQC, similar results were obtained. In general, the IQC premiums calculated under S_I were far below the premiums described in Table 4.1. Regarding S_{II}, the fattening premiums calculated were approximately the fattening premiums paid (Tables 4.1 and 4.2), while the feeder pig premiums calculated, in general, exceeded the original premium of Dfl. 1.0. Under the assumption of S_I, all transfer pricing keys except the one based on total costs (TC), resulted in an extra slaughtering benefit of 17%. This was due to the fact that the premiums paid to the fattening stage were all set at zero, because the extra carcass quality benefit paid exceeded the premium calculated. Under the assumption of S_{II}, the extra net chain benefit of Dfl. 6.8 was redistributed exactly according to the transfer key percentages described at the beginning of each row in Table 4.4.

Similar to IQC, under the assumption of S_I, all IQC^+ fattening pig premiums calculated were below the premium paid of Dfl 31.7. Instead of a premium of Dfl. 0.38 per kg of carcass weight (Table 4.1), the carcass premiums calculated varied from Dfl. 0.17 to Dfl. 0.20. Only under assumption of S_{II}, the fattening premiums calculated equalled or exceeded the original premiums paid. The effect of the group (B) transfer pricing systems was more explicit in the changes in extra net fattening and slaughtering benefits than in the corresponding fattening premiums calculated.

With respect to the outdoor pork chain concept, all transfer keys resulted in a shared extra net chain loss, instead of the favourable position of the fattening stage in the original situation (Table 4.2). The feeder pig premiums calculated exceeded the original premium of Dfl. 23.4 considerably. As all transfer pricing systems showed about equal distributions of profit or loss, with shares ranging between 41% and 59%, the feeder pig premiums calculated were found to be fairly stable.

4.4 DISCUSSION AND CONCLUSIONS

Differentiated chain concepts

Using an economic pork chain simulation model, the effects were analyzed of three differentiated pork chain concepts on both stage and chain profitability. Regarding the outdoor chain concept, results obtained were in accordance with those of other research (De Kleijn et al., 1991; Bens, 1994). For example, Bens (1994) found the same effects on annual numbers of farm production cycles, feed costs and housing costs for fattening pigs.

De Kleijn et al. (1991) calculated a similar increase in outdoor-production costs of about Dfl. 40 per feeder pig and a somewhat higher increase of Dfl. 0.95 per kilogram of carcass weight for outdoor-produced fattening pigs. The latter resulted mainly from the assumption of a higher feeder pig premium paid. However, when comparing the sources of the extra costs, De Kleijn et al. (1991) showed considerably lower labour costs and higher housing costs. Additional labour in the farrowing stage (calculated at +37%) was approximately the same as the 35% Bens (1994) described, but is higher than the 25% De Kleijn et al. (1991) assumed. The biggest difference, however, was found in the additional labour requirements in the fattening stage, where we calculated almost a doubling of labour required. Bens (1994) and De Kleijn et al. (1991) seemed to have used the same percentage for both farm stages. In our calculations, the - daily - supply of roughage, straw and access to outdoor space already increased labour needs per pig sold by about 60%. Further increases originated, among other things, from the smaller scale, more paperwork, and the longer production period per pig sold. The latter sources were seemingly not considered by Bens (1994) and De Kleijn (1991).

In practice, outdoor producers may be induced to - sooner - automatize labour-intensive activities such as feeding. As a result, some components of the extra costs of outdoor pig production calculated in this paper may be lower in reality. On the other hand, larger transportation distances, higher feed prices, lower carcass quality and fewer quota premiums due to smaller batch sizes of outdoor- versus regular-produced pigs (De Kleijn et al., (1991) may imply extra disadvantages in reality, which were not considered in our calculations.

In total, additional chain production costs amounted to Dfl. 1.5, Dfl. 23.2 and Dfl. 84.4 per carcass or pig sold of the IQC, IQC$^+$ and Outdoor pork chain concept respectively. Combined with the extra buyer value, IQC and IQC$^+$ resulted in an increase in net chain results compared with the default chain concept, while the net farrow-to-finish result of the simulated outdoor concept further decreased. The benefits were distributed disproportionately among the chain members, however. Whereas the farm stages in case of IQC and IQC$^+$, and the fattening stage in case of the outdoor chain, reaped all benefits, the slaughtering stage and the farrowing stage respectively incurred disproportionately high losses. Moreover, with respect to IQC and IQC$^+$ the slaughtering stage seemed to incur the majority of the market risks. Because farmers received the concept premiums also for pigs that failed the concept guarantees, for example, because they had been medicated to prevent or cure diseases in too close a period prior to slaughter, this production risk was also incurred in the slaughtering stage. When restricting the conditions at which premiums were paid or when increased sales to the end buyer were supposed under the assumption of a - short-term - price-inelastic demand, net slaughtering results increased. The latter also caused the net chain result to increase without affecting the net results of the supplying farm stages.

Distribution of profit and loss including transfer pricing effects

The concept premiums were recalculated based on compensation of the additional costs plus a share of the extra net chain result. Under the assumption of relatively low market sales, it was found that IQC and IQC^+ premiums paid per feeder pig and per fattened pig sold were too high to assure each chain member of a proportionate part of the net chain benefit. Premiums calculated equalled approximately half of the original premiums. The IQC fattening pig premium was even set at zero, because the additional carcass quality premium already exceeded the extra costs incurred. In contrast, the original outdoor feeder pig premium proved to be too low. Recalculated premiums were about Dfl. 10.0 per feeder pig higher. With respect to IQC and IQC^+, recalculated premiums were only at the original level or higher under the assumption of better market conditions, i.e. higher sales. Based on these findings it can be concluded that market conditions and decisions on shared market and production risks may have a bigger impact on the level of premiums paid than the choice of the various 'cost-plus' based transfer pricing systems presented. Profound market analyses and sales estimates and regular evaluation of chain profitability and transfer prices will be very important (Eccles, 1985).

The different transfer pricing mechanisms used had varying effects on the transferred premiums calculated. In general, variation seemed to be less within groups of either absolute or relative cost-plus based keys, whereas the variation seemed to increase if the concept specifications referred to a special chain participant in particular. Especially in the case of product differentiation, in which the product is discriminated from a standard product sold in the same market, it is often not known what the individual or the interaction contribution of each changed activity to the - extra - end value is. In that case, a comparison of costs between the differentiated and the standard concept may be a compromise for indicating where the surplus may have originated. With respect to product differentiation therefore one might prefer the relative rather than the absolute cost-plus based transfer pricing mechanisms. However, 'no single transfer policy is an ultimate solution for every situation once and for all' (Eccles, 1985). As generally accepted criteria for choosing the best solution for a 'fair' transfer pricing system seem to be lacking, there may always be room for negotiation. This may imply the danger of transfer prices reflecting the power to negotiate rather than the performances of the parties involved (Abdel-Khalik and Lusk, 1974). Moreover, market structures and conditions effecting the distribution of relative market power among chain members will also have their impacts on the distribution of risks and profits or losses.

The cost-plus based transfer pricing system has been described to be one of the most accepted and practical approaches under the conditions of (a) absence of competitive market prices, (b) interest in saving costs of negotiation, (c) the need to implement a policy of pricing final products (Abdel-Khalik and Lusk, 1974). However, general arguments against include the possibility of opportunistic behaviour, of incorporating inefficiencies which may be passed to the consumer, and of impeding the search for technological progress (Abdel-Khalik and Lusk, 1974). Although these limitations may be stronger within a multi-divisional company, they are believed to be less restricting in our case, because once set based on the average - performance -, the presence of multi buyers and sellers will continue to stimulate cost-price decreasing behaviour for each player to increase its profits. Caution, however, is still called for. Other aspects related to the applicability of product- or production-items to be included in payment systems will often involve (a) distinct economic or strategic relevance (Porter, 1985), (b) practical, objective and cost-effective measurability and testability, (c) variability indicating a potential controllability, and (d) goal-consistency, implying a certain natural relation between the item used and the overall goal of the product concept. Besides cost-based transfer pricing systems compensating for a bundle of product- or production-items via a certain economic value per head, transfer keys may also be based on individual product quality parameters, representing economic stimuli varying with the level or degree of the item involved. Examples are the level or absence of pathological lesions or contaminations (Van der Weerd et al., 1989), meat colour or water holding capacity (Hovenier et al., 1993). Whenever a product concept does not allow for the use of specific product value parameters to be included in payment systems, 'cost plus'-based premiums paid per animal may be the - only - solution. This may especially concern the so-called extrinsic or emotional quality aspects, such as animal welfare, which often combine several changes in production and distribution systems not directly related to product characteristics. Moreover, emotional aspects are usually characterized as being difficult to measure and test objectively.

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Chapter 5

ECONOMIC OPTIMIZATION OF PORK PRODUCTION-MARKETING CHAINS I. MODEL INPUT ON ANIMAL WELFARE AND COSTS[1]

ABSTRACT

In recent years animal welfare has become a major concern for consumers. In developing product differentiation policies to respond to this type of concerns, animal welfare preferences have to be related to the cost of production. This paper reports on an application of conjoint analysis to evaluate pig welfare perceptions of both consumer-related respondents and pig welfare experts. Economics of the pig welfare concerns was evaluated, using an economic pork chain simulation model, including the farrowing, fattening and slaughtering stages, and the transportation of pigs between these stages. Results showed that the farm stages farrowing and fattening were considered most important with respect to pig welfare. Important pig welfare attributes included group housing of non-lactating sows, supply of straw and stock density. Respondents were rather heterogenous with respect to their individual quantifications, but no significant difference in response could be found between experts and consumer-related respondents. In total, pig production and distribution costs were increased by 22% to 32% when all pig welfare attributes were included in the pork production-marketing chain. Further research is proposed to balance animal welfare and economic aspects in an integrated manner.

5.1 INTRODUCTION

Consumers show a growing interest in the quality of agricultural products and the manner of production and distribution, including issues such as animal welfare, food safety and environmental pollution (Guither and Curtis, 1983; Ekesbo, 1992; Barkema, 1993). Demands of this type refer to a large extent to the upstream farm stages of the so-called production-marketing chain, requiring that those consumer preferences be incorporated in all stages involved (Den Ouden et al., 1996a). To anticipate this development, the potential structural and economic effects on the stages of the production-marketing chain should be explored. Regarding product development policies, trade-offs have to be made between preferences and profitability. This paper elaborates on animal welfare in the pork chain, including the evaluation of its perception and economics.

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To anticipate the concerns that are important regarding pig welfare and to evaluate the level of importance, one can consult scientific literature and pig welfare experts. However, product development strategies can only be successful if producers adopt a consumer-oriented approach, as the consumer ultimately decides what food products are bought (Steenkamp, 1987). Moreover, consumers may evaluate product attributes differently from experts (Kramer, 1990). While the mood of the general public is difficult to gauge, one indication is a proliferation of pressure groups dedicated to improving animal welfare. As some of these groups are known to carry on successful campaigns, they are assumed to both represent and influence the perception of various consumer groups. For this reason they may serve as indicators of public concerns. In this paper, conjoint analysis was used to study the evaluations of pig welfare experts and consumer-related respondents with respect to pig welfare (Green and Srinivasan, 1978).

To evaluate the economic impact of the pig welfare concerns, an economic pork chain simulation model was used (Den Ouden et al., 1996b). The model includes a farrowing stage producing feeder pigs, a fattening stage producing fattened pigs, and a slaughtering stage. Also transportation between the stages was considered. Pig welfare evaluations and economic calculations, therefore, concerned sows, young piglets and pigs during the growing to finishing phase, during transportation and in the lairage room prior to slaughter. In using the pork chain model instead of models simulating the separate stages of the chain, interstage relations could also be taken into account. Both the animal welfare evaluations and the costs of the corresponding attributes will serve as input values in an optimization model (dynamic linear programming); which will be discussed in a following paper. The current paper presents the pig welfare perceptions and the corresponding costs in the various stages of the pork chain.

5.2 MATERIAL AND METHODS

5.2.1 Pig welfare concerns

Extensive literature is available on how to assess animal welfare (Smidt, 1983; Fraser and Broom, 1990). Indicators described include productivity (e.g. growth rate and reproductive performance), physiological (e.g. body temperature, heart rate and blood composition), veterinary (e.g. mortality, morbidity and external injuries of the animal) and ethological variables (relating to behavioural observations of the animal) (Smidt, 1983; Gloor, 1988). Although the various indicators have all their pros and cons, most authors propose an integrated multidimensional approach (Smidt, 1983; Gloor, 1988; Fraser and Broom, 1990). However, the various indicators are (a) used to assess the pig welfare effects of different attributes in the various stages of the pork chain, (b) estimated under varying - experimental - conditions and (c) not easy to weigh against one another (Smidt, 1983). Moreover, members of retail organizations and other consumer-related groups may not be fully familiar with - the interpretation of - these scientific indicators (e.g. Kramer, 1990). Overall, it was considered less appropriate to use - a combination of - these parameters to assess the pig welfare perceptions of both consumer-related and scientific respondents on a unique and comparable scale.

Instead, a questionnaire was developed. Based on scientific literature (e.g. Van Putten and Elshof, 1978a, 1978b; Sybesma, 1981; Gloor, 1988, Fraser and Broom, 1990), popular press papers, material published by animal welfare pressure groups (Anonymous, 1994), characteristics of pork products available in the marketplace (e.g. Anonymous, 1991), and consultation of experts, the pig welfare concept was subdivided into various underlying attributes along the pork production-marketing chain. Consequently, attributes were subdivided into two or three levels. The values of attribute levels were based on literature or - variation in - characteristics of pork products available in the marketplace. Regarding some attributes, however, quantified levels were lacking or vague. Therefore, at the end of the questionnaire each respondent was asked to quantify certain attribute levels in open-end questions. An overview of the attributes with corresponding levels is presented in the 'results'-section (Table 5.3).

The attributes selected were subdivided into two major groups, without the intention to base these categories on ethological grounds. One group concerned attributes related to social contacts with conspecifics or human beings, and the other involved attributes related to the surroundings of the pigs. Attributes in the 'social contacts' group included the mixing of socially unfamiliar animals, the weaning age of piglets and the way in which pigs are handled during transportation and in the slaughterhouse. According to Fraser and Broom (1990) 'a traumatic event encountered by each piglet on commercial farms is weaning'. They describe belly-nosing and suckling behaviour with other piglets as indicators of the fact that early weaning must have considerable effects on piglets, resulting in poor welfare. Similar effects of early weaning were described by Schmidt and Adler (in Sybesma, 1981). Another welfare problem arising at the time of weaning is fighting caused by mixing piglets from different litters (Fraser and Broom, 1990). The effects of this problem may be greater when older pigs are mixed, since they can inflict more serious injuries on each other. Regrouping a socially stable group of animals may increase fighting behaviour to re-establish a new social rank (Grandin, 1980; Karlsson and Lundström, 1992). Although fighting is rare during transportation, each time the truck stops to load pigs on another farm, mixed pigs may start fighting again (Fraser and Broom, 1990). Moreover, the screaming noises (Grandin, 1980) of the newly loaded and unknown pigs may cause additional stress. Rough handling, e.g. using electric prodders to move the pigs, may save labour time but cannot be regarded as beneficial to the welfare of the animal. Van Putten and Elshof (1978) reported an increase in heart rate by a factor of 1.5 when an electric prodder was used.

Surroundings-related attributes involved the type of housing, the stock density in pens, lorries and lairage rooms, the availability of straw, roughage and outdoor space, illumination and ventilation devices, the slope of the (un)loading bridge and the use of water sprays in lairage. In general, providing more (concrete) floor space, straw as distraction, day-night rhythm of illumination and outdoor space are considered beneficial to the pig's welfare (Bäckström, 1973; Grandin, 1980; Sybesma, 1981; Vellenga et al., 1983; Fraser and Broom, 1990). Bäckström (1973) describes the favourable effects of feeding roughage to pigs. Non-lactating sows can be housed individually, either tethered or in cubicles, or in groups. Group housing provides more freedom of movement and social contacts (Gloor, 1988; Fraser and Broom, 1990; Ekesbo, 1992). Van Putten and Elshof (1983) found that pigs when kept in complete darkness, showed more lying, less social and less playing behaviour and more tail-bitting compared with pigs which were kept in rooms illuminated at 1 or 25 lux. Grandin (1980) also stresses the importance of illumination, both as far as the animal itself is concerned and when handling them. Pigs dislike climbing and descending steep loading bridges. Reducing the angle below 20° makes (un)loading much easier for the inexperienced animals. A lifting-platform will do so even more (Van Putten and Elshof, 1978; Fraser and Broom, 1990). If there are high loading densities during transport, not all pigs are able to lie down and rest. The close body contact in combination with forced association with strangers and insufficient ventilation can be quite harmful to the animals (Lambooy and Engel, 1991). Warriss et al. (1992) recommend a 2 to 3 hour-resting period in lairage prior to slaughter to let the pigs recover from transportation stress. Showering the pigs in lairage seems to have a beneficial and tranquillizing effect on the animals (Van Putten and Elshof, 1978). When pigs are kept in lairage overnight, carcass yield is reduced, even if the animals are given food. Warriss et al. (1990) suggest that to some degree this is directly related to the stress associated with keeping them in an unfamiliar environment. With respect to some attributes, classification under one of both headings may be open to question. An example is whether or not to move piglets from the nursery to a rearing pen at weaning.

5.2.2 Evaluation of pig welfare concerns using conjoint analysis

Conjoint analysis pursues to quantify and predict the respondent's overall judgement (e.g. on pig welfare) on the basis of the concept attributes. Each possible combination of attribute levels represents an alternative concept of pig welfare, a so-called pig welfare 'profile'. For example, seven attributes, each with two levels, would yield a total of $2^7 = 128$ possible profiles (full factorial design). It is obvious that a respondent is not able to differentiate between these profiles. When using fractional factorial designs in conjoint analysis, only 8 orthogonal alternative combinations of these 7 uncorrelated attributes have to be evaluated to estimate main effects (Steenkamp, 1985). A description of the composition of alternative combinations can be found in Addelman (1962). Ordinary least-squares (OLS) regression analysis is used to break down the respondent's overall judgements on the set of concept alternatives into the contribution of each attribute level. The contributions of the various attribute levels to the overall judgement are called part-worths, and are directly compatible with each other. The difference between the part-worths of the various levels of an attribute is equal to the regression coefficient. Besides additive models, it is also possible to take potential interactions between attributes into account. In general, conjoint analysis offers the advantages of allowing for quantitative evaluation of subjective and differently-scaled attributes using only a limited number of alternative profiles, consideration of interactions and testing for consistency in the answers of the respondents (Hair et al., 1990, Green and Srinivasan, 1978). Compared to compositional methods such as direct questioning, conjoint analysis provides the advantage of higher realism because attributes are evaluated in combination with one another, as in the 'real world', instead of separately (Huber et al., 1993). Other advantages may refer to the absence of groups effects, reducing the likelihood of socially desired answers and probably being less time-consuming than repeated rounds of group- or individual elicitation procedures. Based on their predictive performances, conjoint techniques were often found to give better results than the compositional methods (Huber et al., 1993).

In the questionnaire one case was developed for each of the four stages of the pork production-marketing chain. Based on the literature (Fraser and Broom, 1990; Lambooy and Engel, 1991) and discussions with experts, interactions were assumed between (1) the attributes 'mixing socially unfamiliar piglets at weaning', 'moving piglets from the nursery pen to rearing pens at weaning' and 'the weaning age of the piglets' in the farrowing stage, and (2) between the attributes 'stock density' and 'ventilation' during transportation. Moreover, an additional case was added to the questionnaire to test on possible interactions between the attributes whether or not to mix socially unfamiliar pigs at the various stages of the pork chain. Additive models were assumed for the fattening and the slaughtering cases. The fattening, transportation and slaughtering cases each included 11 profiles, while the farrowing case involved 19 profiles. The slaughtering case of the questionnaire is presented in Appendix 5.I as an example.

Per case, each profile had to be judged on an interval scale ranging from 0 to 100. Respectively 8 and 16 profiles per case were used to estimate the part-worths of the attribute levels, while the remaining 3 so-called 'hold-out' profiles served to test the predictive validity of the estimated models. The predictive validity indicates the fit of the estimated part-worths to the respondent's real values of the hold-out profiles (Steenkamp, 1985), and is assessed in terms of Pearson's product moment correlation coefficient (interval scaled data) and Kendall's τ rank correlation coefficient (hierarchically ranked data) (Siegel, 1956). Both coefficients also served as indicators of the internal validity of the models, i.e. the conformity between the input values of the 'non hold-out' profiles and the estimated values based on the assessed part-worths. Moreover, for each case, the Kendall coefficient of concordance, W (Siegel, 1956), was calculated to measure the association among the sets of ordinal rankings of the respondents.

To translate stage results into chain results, each respondent was asked to directly quantify the relative importance of each stage with respect to the overall pig welfare throughout the chain system. That is, respondents were asked to do divide a total of 100 points over the four stages farrowing, fattening, transportation and slaughtering according to their perception of the relative importance of each stage regarding the overall pigs' welfare from farrowing to slaughtering. By multiplying the estimated regression coefficient of each attribute with the relative contribution allocated to the corresponding stage, the pig welfare regression coefficients of the chain were obtained. Moreover, each respondent was asked to quantify the attribute levels of his/her 'ideal' profile with respect to pig welfare. The questionnaires were sent to 11 Dutch respondents, 6 of whom could be considered pig welfare experts, and the other 5 represented animal welfare pressure groups and retailers (denoted as the consumer-related group). Multivariate ANalysis Of VAriance (MANOVA) was used to test whether the regression coefficients of the consumer-related group of respondents differed significantly from those of the experts.

5.2.3 Economic pork chain simulation model

The economic effects of the pig welfare related attributes were calculated, using an economic pork chain simulation model (Den Ouden et al., 1996b). The model was developed to simulate technical and economic performances in both individual stages and pork production-marketing chains as a whole, taking into account interstage relations between the various stages. Interstage relations are defined as the way in which the performance of a stage is influenced by the activities performed or affected in other stages of the chain. Examples of interstage relations include the relation between farm size and transportation efficiency and between the distribution of fattened pigs over live weight classes at the end of the fattening period and carcass quality and value in the slaughterhouse. Besides variables representing interstage relations, input and output variables are distinguished. They represent biological, technical and economic parameters.

Input variables concern input on both farm lay-out and technical performance, such as sow reproduction and replacement information in the farrowing stage. The farm lay- out, including housing and feeding facilities, is related to the labour required for operating the farm stages (Den Ouden et al., 1996b). Based on the input values, the technical output is calculated. An important technical output variable in the farm stages is the size of the farm. Combined with other technical output, the farm size determines how many pigs can be sold per year. In this way, it affects both the economic results of the farm and the number of feeder pig suppliers in the fattening stage and hog suppliers per lorry respectively. Elbers (1991) found that the number of feeder pig suppliers per compartment of a fatting farm influenced the productive performance. Effects on both daily gain, mortality rate and drug use in the fattening stage and the prevalence of pathological lesions in the slaughtering stage were quantified.

With respect to the fattening stage, average daily growth rate can be considered a major input variable. Growth rate is related to the feed conversion ratio and the number of production cycles per year. Moreover, technical output of the farm stages, such as the number and live weight of pigs sold per week, also influences the efficiency and costs of transportation and slaughtering.

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. Based on the demand for pigmeat, carcasses are assigned to the various processing options, thus determining the processing costs and the carcass value. Finally, economic output includes overall production costs per stage and for the chain as a whole. Costs calculated include labour costs, interest, depreciation, raw material costs and other costs, such as costs of feed, drugs, water and electricity. They can vary proportionally with the scale of operation, such as feed costs, or remain constant over a specified range of activities, such as some management labour costs and cost of housing facilities. Some major technical and economic input and corresponding output is described in Appendix 5.II. More details on the simulation model can be found in Den Ouden et al. (1996b).

5.3 RESULTS

5.3.1 Estimated pig welfare contributions

Questionnaires were completed by 7 of the 11 respondents. The non-respondents involved one expert and three members of the consumer-related group. At the individual level, attribute importance weights were calculated to indicate the relative importance of each attribute per case (Cattin and Wittink, 1982). In Table 5.1 the three attributes with the highest average importance weights per case are presented.

The respondents showed a fairly high concordance with respect to the attributes they regarded as most important in each case. For example, in the farrowing case, the attribute 'individual or group housing of sows' was valuated at the highest importance score by 6 out of 7 respondents. In general, social contacts related attributes, including the way of handling the pigs and whether or not unfamiliar pigs were mixed, were considered particularly important during transportation and prior to slaughtering. In the farrowing and especially in the fattening stage, the surroundings related attributes were considered most important.

Table 5.1 The three pig welfare related attributes per case with the highest average importance weights.

Farrowing	Importance weight	Fattening	Importance weight
1. Housing non-lactating sows	31.6	1. Supply of straw	24.2
2. Mixing of unfamiliar pigs	17.1	2. Total:concrete space	21.0
3. Weaning age	12.2	3. Illumination	19.1
Transportation	**Importance weight**	**Slaughtering**	**Importance weight**
1. Handling	30.2	1. Handling	26.9
2. Mixing of unfamiliar pigs	19.9	2. Mixing unfamiliar pigs	21.2
3. Stock density	17.4	3. Water spraying lairage	13.7

Table 5.2 presents the relative importance of each stage with respect to the overall pig welfare throughout the chain, as quantified per respondent. In general, the farm stages fattening (32.6) and farrowing (29.6) were thought most important with respect to pig welfare. However, the respondents' individual perceptions varied considerably. Whereas respondent 7 considers the fattening stage most important with respect to pig welfare (55), respondent 2 assigns the largest weight to the slaughtering stage (40) (Table 5.2). The relative importance weights per stage were used to convert the regression coefficients per stage into chain results adding up to a total maximum of 100 per respondent. Correction was made for the inter-stage interactions found for mixing pigs in the subsequent stages of the chain. It is emphasized that the pig welfare coefficients thus represented estimated pig welfare improvements additional to the pig welfare level in the default situation which varied between respondents ranging from -2 to 20 points on a scale from 0 to 100 per case.

Not one of the respondent's data resulted in significant interactions in the farrowing case ($p > 0.1$). The fit of the additive model to the individual data was rather good; Pearson's r was 0.973, on average, with a standard deviation of 0.020. The additive model was significant at $p = 0.05$ for 6 respondents and at $p = 0.1$ for 1 respondent. Both Pearson's r and Kendall's τ of the additive models for the fattening and the slaughtering cases and of the multiplicative design for the transportation case equalled 1 for all respondents, indicating a very good fit of the estimated models to the input data. The predictive validity of the estimated models may be even more important than the internal validity (Steenkamp, 1985). On average, Pearson's r and Kendall's τ varied from respectively 0.830 (slaughtering case) to 0.982 (transportation) and from 0.619 (transportation) to 0.878 (farrowing case). In total, the percentage of cases with a significant predictive validity ($p <= 0.1$) equalled 79% and 68%, as measured by Pearson's r and Kendall's τ respectively. In general these scores are fairly good.

Table 5.2 Individual and average relative importance weights with respect to pig welfare per stage of the chain.

	Expert respondents					Consumer-related respondents		
Stage	1	2	3	4	5	6	7	Average
Farrowing	40	15	17	30	45	35	25	29.6
Fattening	30	15	23	35	40	30	55	32.6
Transportation	20	30	33	20	10	20	10	20.4
Slaughtering	10	40	27	15	5	15	10	17.4
Total	100	100	100	100	100	100	100	100

The Kendall coefficients of concordance, W, equalled 0.69, 0.59, 0.72 and 0.70 for the farrowing, fattening, transportation and slaughtering case respectively and were all significant ($p < 0.01$), indicating that the respondents assigned welfare scores that resulted in quite similar ordinal rankings of the pig welfare profiles of each stage of the chain. With respect to the interval scaled pig welfare scores and the pig welfare regression coefficients estimated from those, MANOVA of both the original regression coefficients per case and of the pig welfare coefficients calculated for the chain as a whole did not yield a significant difference ($p > 0.1$) between the two groups of respondents. This implies that the expected contrast between the experts and the consumer-related group could not be proved by the data of this study. Because the latter results will be influenced by the small sample size of respondents and for the use of sensitivity analysis, the chain pig welfare coefficients of two respondents, presented in Table 5.3, were selected for further analysis. Their selection was based on (1) a high internal and external validity as assessed by Pearson's r and Kendall's τ, (2) them originating from a different group, and (3) a high consistency between the directions (+ or -) of the estimated coefficients and the effects of the attributes in the ideal profile described.

The attributes presented in Table 5.3 are in order of decreasing chain pig welfare coefficients of the consumer-related respondent. The values of attribute levels that were quantified in open-end questions are also shown. In correspondence to the general perception (Table 5.1), both the consumer-related respondent and the expert regarded the fattening stage as most important with respect to the overall welfare of the pigs.

Both respondents favoured especially the surroundings related attributes in this stage. On a scale from 0 to 100, the absolute total scores varied considerably, however (55.3 versus 35 respectively (Table 5.3)).

Table 5.3 The estimated pig welfare coefficients based on the data of a consumer-related respondent (respondent 7 in Table 5.2), denoted W_c, and an expert (respondent 4 in Table 5.2), denoted W_e. The levels of each attribute are denoted Δ_C and Δ_E.

			consumer-rel. resp.	expert	
	Default	Δ	W_C	W_E	Cost coefficient
Farrowing					
social contacts					
- mixing socially unfamiliar pigs at weaning	Yes	No	1.29	8.34	1.39[1]
- weaning age (weeks)	4	6	1.00	4.53	8.76[1,4]
surroundings					
- outdoor space (m^2/sow)	0	5/15[2]	5.69	2.04	1.98/4.70
- group housing	No[3]	Yes[a]	3.92	8.88	2.78
- total floor space nursery (m^2)	3.75	6.5	3.18	0.54	2.39
- concrete floor space nursery (m^2)	0	4			0.34
- housing in cubicles	No[3]	Yes[a']	3.15*	2.57*	2.16
- supply of straw (kg/pig/week)	0	1.4/7[2]	3.05	2.66	3.20/5.89
- total floor space non-lactating (m^2)					
. tethered housing or in cubicles	1.1	1.4	2.35	-2.13	0.25
. grouphousing	2.0	3.0			0.84
- illumination standards (lux/12 h./day)	No[5]	20	2.54	1.69	0.42
- moving at weaning	Yes	No	2.15	1.33	2.09
Maximum welfare points			25.2	30.0	
[4] 2 feeder pig suppliers instead of 1					3.89[1]
Fattening					
social contacts					
- mixing socially unfamiliar pigs start cycle	Yes	No	3.21	1.67	3.63[1]
surroundings					
- outdoor space (m^2/pig)	0	1.1/2.5[2]	16.31	7.22	8.12/13.51
. longitudinal vs. cross-sectional					4.26
- total floor space longitudinal (m^2/place)	0.57	0.9	12.96	1.67	8.08
- total floor space cross-sectional (m^2/place)	0.57	0.9			5.29
- concrete floor space (m^2/place)	0	0.4			1.95
- supply of straw (kg/pig/week)	0	0.1/1[2]	10.18	11.67	5.88/28.25
- illumination standards (lux/12 hours/day)	No[5]	20	6.55	8.33	0.79
- supply of roughage (kg./pig/dag)	0	(1/10)[6]/0.5[2]	5.16	3.89	9.39/12.59
- ventilation automated	No	Yes	0.98	0.56	1.57
Maximum welfare points			55.3	35.0	

[1] The additional costs per pig were partly incurred in a subsequent stage.

[2] Representing the highest attribute levels of the consumer-related respondent and the expert respectively.

[3] In the default situation, non-lactating sows were tethered.

[4] Additional costs incurred when feeder pigs were supplied by 2 instead of 1 supplier.

[5] In the default situation it was assumed that (artificial) lights were used for about 2 hours and 1 hour per day in the farrowing and fattening stage respectively. An average illumination of 31, 48, 44 and 36 lux per m^2 was provided in farrowing, gestation, breeding and fattening rooms respectively.

[6] The amount of roughage fed to hogs was quantified at one tenth of the daily amount of concentrates.

[a-a'] Mutually exclusive attributes; sows can be housed in either cubicles or groups.

Table 5.3 Continued.

	Default	Δ	consumer-rel. resp. W_C	expert W_E	Cost coefficient
Transportation					
social contacts					
- handling	rough	quiet	6.10	6.48	0.08
- mixing socially unfamiliar pigs at loading	Yes	No[a']	0.82	5.35	1.18*
- loading on various farms	Yes	No[a]	0.82	2.54	3.21
surroundings					
- stock density (kg/m²)	300	235[a']	0.99	2.25	0.69*
- ventilation automated	No	Yes	0.33	0.56	0.06
- interaction loading density x ventilation	-	-	0.99	2.82	
Maximum welfare points			10.05	20.0	
Slaughtering					
social contacts					
- handling	rough	quiet	5.30	3.29	1.3
- mixing socially unfamiliar pigs during lairage	Yes	No[b]	1.56	3.29	0.016
surroundings					
- stock density (kg/m²)	300	235[b']	1.25	2.46	0.004*
- automated lifting platforms	No	Yes	0.93	2.63	0.04
- water spraying during lairage	No	Yes	0.93	1.63	0.036
- keep overnight	Yes	No	0.09	0.08	-0.14
- resting period (hours)	2	4	-1.25	1.63	0.016
Maximum welfare points			10.05	15.0	
Interaction mixing unfamiliar pigs:		-			
- farrowing x fattening		-	-0.3	-1.7	
- farrowing x transportation/slaughtering		-	-0.6	-1.7	
- farrowing x fattening x transport/slaughtering			0.3	3.4	
Total maximum welfare points			100	100	

[a,b] Mutually exclusive cost coefficients. The cost coefficient that is excluded in denoted *.

Individual differences concerned particularly the access to outdoor space. The consumer-related respondent appreciated this attribute more than the expert, who assigned, moreover, a lower pig welfare coefficient to a bigger amount of outdoor space per animal. The same contrast was shown for outdoor space in the farrowing case. Additionally, the consumer-related respondent considered an increase of the resting period from 2 to 4 hours non-beneficial to the welfare of the pigs, as can be seen from the negative coefficient in Table 5.3. Similar to the general perception, both the consumer-related respondent and the expert considered the social contacts related attributes the most important pig welfare ones in the transportation and slaughtering stages.

5.3.2 Economics of the pig welfare attributes

The economic effects of the pig welfare attributes are presented per animal (Table 5.3) and represent the additional costs resulting from changing the level of one pig welfare attribute from the lowest (default), or expected least preferred level, to the highest, or expected most preferred level. In calculating the economic effects the farm sizes were kept constant. Regarding attribute levels quantified in open-end questions, the economic effects of the highest values quantified by the expert were calculated as well.

Beforehand there were no estimations of the premium price consumers would be willing to pay for these types of pork products. For some attributes, changing the levels also implied a change in the quality of the carcasses. In this case, the effect on the net returns could be quantified. However, most attributes were valuated only on the basis of the additional costs incurred. Therefore, the economic effects were further denoted as 'cost coefficients'.

In the default situation, total production costs equalled approximately Dfl. 120 per feeder pig sold, Dfl. 188.7 per fattened pig sold, Dfl. 3.6 per transported hog and Dfl. 45 per carcass slaughtered, processed and sold. Total chain production costs therefore added up to Dfl. 357 per pig from farrowing to slaughter. Some important technical and economic output results of the default situation are presented in Appendix 5.II.

Social contacts related attributes

The attributes that were classified under the 'social contacts' heading had considerable economic effects, especially in the farrowing, transportation and slaughtering stages. In the farrowing case the highest additional costs were incurred by changing the weaning age from 4 to 6 weeks. In doing so, the average number of litters produced per sow per year decreased from 2.29 to 2.10. Simultaneously, the cost of artificial insemination declined. On the other hand, the increased lactation period caused the housing costs per sow per year to increase by Dfl. 28 as result of a need for more - relatively expensive - nursery pens. Analogously, the feed costs for sows increased by Dfl. 29.8 per sow per year because the amount of feed consumed increased. The feeding costs for piglets decreased, however, resulting in a net decrease in total feeding costs of Dfl. 60.2 per sow per year. In total, the production costs per feeder pig sold increased by Dfl. 8.76 (Table 5.3). Because of the smaller number of litters produced per sow per year the number of feeder pigs available for (weekly) supply to the fattening stage decreased. As a result, the transportation costs increased by Dfl. 0.02. Moreover, 2 feeder pig suppliers instead of 1 were needed to provide the total number of feeder pigs demanded per fattening room. Due to lower performance at the fattening stage (Elbers, 1991) additional costs of Dfl. 3.89 per pig were incurred from fattening to slaughtering (Table 5.3).

In case mixing of socially unfamiliar pigs was no longer allowed at weaning or at the start of the fattening period, it was assumed that the variation in daily gain of fattening pigs increased by 10%. As a result, the number of production cycles decreased slightly from 2.94 (Appendix 5.II) to 2.93. Because of the (interstage) relation between live weight and carcass weight, more carcasses came in the upper low and upper high carcass weight classes which were valuated at a lower price. In total, the production costs per pig increased by Dfl. 0.53, 17% of which were incurred at the fattening stage, and 83% at slaughtering the pigs and selling the carcasses or cuts at a lower value. Interstage effects like these, i.e. if part of the additional costs per pig was incurred in more than one stage, are indicated by '1' in Table 5.3. As it was no longer allowed to foster weaned piglets from large to small litters, housing costs were assumed to increase by Dfl. 0.86 per feeder pig and Dfl. 2.67 per fattened pig sold respectively. Moreover, lower truck occupation rates caused transportation costs to increase by Dfl. 0.43 for feeder pig transportation and by Dfl. 1.18 (Table 5.3) per pig transported to the slaughterhouse. In total, not mixing socially unfamiliar pigs resulted in additional costs of Dfl. 1.39 per feeder pig and Dfl. 3.63 per fattened pig (Table 5.3).

The proposition not to load pigs on more than one farm had the biggest economic impact in the transportation stage. Based on an average batch size of 60 pigs per farm, the occupation rate of the truck dropped dramatically causing the transportation costs to increase by Dfl. 3.21 per transported pig. This implied almost a doubling of the costs in the default situation. By handling pigs more quietly on their way from the lairage rooms to the restrainer in the slaughtering stage, it was assumed that the number of pigs slaughtered per hour was decreased by 10%. As a result, the slaughtering costs increased by Dfl. 1.30 per animal.

Surroundings related attributes

In general, the surroundings related attributes had a major impact on the economics, especially in the fattening stage. In the slaughtering stage, however, preventing pigs from being kept overnight yielded an economic benefit. This was related to the savings of the compensation of 1% of the carcass weight paid to the farmer for pigs that are kept overnight. Assuming that, in the default situation, approximately 5% of all pigs slaughtered are kept overnight this means a savings of Dfl. 0.14 per average pig.

In the fattening stage the supply of straw, roughage and access to outdoor space had the biggest effect on the additional costs incurred per pig (Table 5.3). Regarding daily and weekly supply of respectively roughage and straw, extra labour costs were primary causes. In total, the additional production costs incurred added up to Dfl. 9.39 and Dfl. 12.59 at daily amounts of roughage of one tenth of the concentrates supplied and 0.5 kilogram per pig respectively.

If access to outdoor space had to be available in the fattening stage, barns had to be built longitudinally instead of cross-sectionally. In longitudinal barns, - the feed troughs of - all pens are placed parallel to the central alley, instead of being placed at right angles, as is done in cross-sectionally built barns. In this way, each pen has an individual opening to the outside. Housing the same number of pigs in longitudinal barns increased the housing costs by Dfl. 4.26 per pig (Table 5.3). This resulted from the need to build more barns, and the higher ratio of relatively expensive outside walls. Similar effects of supplying straw and access to outdoor space were found in the farrowing stage.

Interrelated cost coefficients

Regarding their economic effects, some attributes were related to each other. For example, the average illumination per square metre varies with the area of the pen. As a result, when adding extra floor space in combination with the higher illumination standards, total additional illumination costs increased from Dfl. 0.28 and Dfl. 0.57 to Dfl. 0.42 and Dfl. 0.79 per feeder pig and fattened pig sold respectively (Table 5.3). Moreover, because of the smaller number of feeder pigs and fattened pigs sold per year, the combination of other farm attributes with an increase in weaning age, caused the additional costs incurred per pig sold to be higher than the sum of the extra costs presented in Table 5.3. A exception was formed by the combination with not moving the piglets at weaning. Because in this case already more - expensive - nursery pens were needed to rear piglets in, production costs were 'only' increased to Dfl. 9.22 in combination with increasing the weaning age to 6 weeks.

Besides interacting relations between attributes, other attributes were mutually exclusive with respect to their cost coefficients (denoted *). For example, if pigs were kept together during transportation, or if pigs were to be loaded on one single farm only, the stock density of the lorry decreased to a level of 235 kilograms per m^2 or even lower. The additional costs of a lower stock density, therefore, can be avoided in combination with the other two attributes.

5.4 DISCUSSION AND CONCLUSIONS

Using a chain model instead of separate stage simulation models offers the advantage of taking interstage relations into account. Interstage relations were quantified for both economic effects and pig welfare concerns. The contributions of the various concerns on the welfare of pigs along the stages of the pork chain were quantified, using a questionnaire developed and analysed by conjoint analysis of multi-attribute parameters.

Conjoint analysis

Conjoint analysis is especially suitable for handling variables that are qualitatively specified or evaluated on different scales. This was especially suitable as the pig welfare predictor variables included both nominal and ratio scaled attributes and, as pig welfare, as a response variable, seems a qualitative notion itself. Moreover, with respect to product development it is the consumer's perception of pig welfare that is also (i.e. more) important (Sybesma, 1981), being a nonmetric and personal notion in itself. Potentially, consumer's perception could even be in conflict with scientific indicator criteria or expert perceptions based on these criteria (Kramer, 1990). Based on the valid and useful results obtained, this method seems to be a promising tool for broader application in livestock farming research. Examples may range from evaluation of exterior characteristics of livestock to the assessment of the relative importance of qualitative factors e.g. in disease control or animal replacement decisions.

Using multi-variate analysis of variance, no significant difference could be found between the pig welfare coefficients of the scientific experts and the group of consumer-related respondents ($p > 0.1$). The rather small sample size will have influenced the group results. Because in the Netherlands the number of pig welfare experts, well-informed members of animal welfare pressure groups and retailers is limited, only relatively few people could be approached in the first place. However, the individual analyses already yielded interesting information, suitable for further analysis. This disaggregate or individual approach is an especially attractive feature of conjoint analysis (Hair et al., 1990).

Validity of pig welfare results

In general, the predictive validity of the estimated models was good, indicating that the respondents were quite capable of a consistent evaluation of the pig welfare attributes. On average, Pearson's r and Kendall's τ equalled 0.92 and 0.78 respectively. Differences in validity observed between respondents could partly have resulted from different perceptions of attribute interactions. The expected attribute interactions that were incorporated in the questionnaire were not always mentioned in the open-end questions on potential interactions. Moreover, respondents mentioned interactions not included in the questionnaire or interactions with attributes that were not included either. Although the attributes and attribute levels incorporated in the models have been carefully selected, there will be attributes excluded that affect both the welfare of the pigs and the behaviour of people in response thereof in the marketplace (Cattin and Wittink, 1982).

Based on a heart rate increase, Van Putten and Elshof (1978) found that the loading bridge had a major effect on the pigs' welfare during transportation. Second in line was the use of electric prodders, the effects of which were included in the attribute 'handling' which was considered most important in our study. In our case, 'handling' also included the (in)appropriate illumination of areas between which pigs had to be moved. The latter was treated separately by Van Putten and Elshof (1978). Being - explicitly - discussed in many publications on pig welfare (Sybesma, 1981; Gloor, 1988; Fraser and Broom, 1990; Ekesbo, 1992), the finding of the type of housing being perceived as the most important sow welfare attribute, seems justifiable. In their general discussion, Fraser and Broom (1990) mentioned weaning, mixing of unfamiliar piglets and the amount and quality of space provided to fattening pigs in particular. In this study the same items scored high in the list of most important pig welfare attributes.

Validity of economic results

Cost coefficients calculated may not be all equally or fairly comparable to one another. The levels of some pig welfare attributes represent situations that are not common in practice. This, for example, holds for the supply of large amounts of straw, roughage or outdoor space. Moreover, as outdoor pig farming is recent and not (yet) as widely adopted as the traditional system, research on more (labour and cost) efficient working procedures and operating devices has just started. Similar arguments may, for example, hold for the measure of not keeping pigs at the slaughterhouse overnight or the requirement of loading pigs for transportation on one single farm only. For the first attribute (keeping pigs overnight at the slaughterhouse) no quantitative information was available on the additional measures needed to realize this attribute level. As a result, only the cost savings from not compensating the farmer could be taken into consideration in calculating its economic effect. However, the extra costs of additional measures preventing pigs from staying overnight may prove to be - far - more expensive than the compensation rates paid to the farmer.

Lack of comparable economic data especially concerns the transportation and slaughtering stages. Moreover, pig welfare economics described in literature often concerned complete systems rather than individual attributes or other - economic - performance indicators. Although some of their assumptions differed from ours, in general, the findings of Lazarus et al. (1991) are in line with the results described in this paper. They found that the straw bedding system had the biggest (negative) economic effect, followed by the outdoor system. All alternative pig welfare systems they evaluated in swine farming, reduced the return to management and risk. Van 't Klooster (1987) reported additional housing costs ranging from Dfl. 1 to almost Dfl. 6 per fattened pig per year for remodelling fully slatted floor barns (0.54-0.60 m^2/pig) into partly slatted floor barns (0.68-0.75 m^2/pig). These figures are in line with the cost effects described in this study.

Changes in farming, transportation and slaughtering systems may influence technical performance. Although production results cannot be considered valid indicators of animal welfare, in reverse, it may be expected that measures aimed at improving the well-being of animals will reduce the harmful effects of poor welfare, such as injuries, mortality or other production losses. For example, solid floors with straw bedding were associated with reduced mortality, morbidity and especially external injuries of piglets in farrowing pens (Vellenga et al., 1983). Not mixing pigs was related with improved meat quality and reduced skin lacerations (Karlsson and Lundström, 1992). Lambooy and Engel (1991) reported various effects, including interactions, of showering, loading density and ventilation during transport on the pigs' condition and meat quality. However, observations indicating a reverse relation between pig welfare related farming systems and production results have also been described. For example, Le Denmat et al. (1994) and Mortensen et al. (1994) reported higher piglet mortality and lower feed efficiencies in outdoor pig production systems. In this paper, effects of pig welfare related attributes on technical performance have not been taken into consideration. Future research on this type of effects seems useful, however, as economically optimal solutions may alter when production considerations make a costly attribute less or more attractive. So far, the additional costs calculated in this paper can be used as an indication of the level of the premium price buyers must be willing to pay and/or the improvement in technical performance needed to break-even.

Balancing pig welfare concerns and economics

In general, respondents showed a high degree of concordance with respect to the attributes that were considered most important to the welfare of pigs. Examples included the supply of straw and group housing of non-lactating sow in the fattening and farrowing stage respectively, and the way of handling the pigs and whether or not unfamiliar pigs were mixed during transportation and prior to slaughtering. The economic effects of these attributes were rather big however. In case all attributes were added, total additional costs incurred per pig from the farrowing to the slaughtering stage amounted to 22% to 32% of the total chain production costs in the default situation (Dfl. 357).

Besides information on pig welfare effects and related economics of the separate attributes and of their combined total, it will be interesting to explore how pig welfare can be maximized at minimum cost going from the default situation to the maximum. Effects of intermediate requirements of pig welfare on structure, economics and stability of pork chain concepts will reveal useful information for establishing pig welfare policies for both government and businesses. In a following paper, a dynamic linear programming model will be presented which will deal with these issues.

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Appendix 5.I Slaughtering case of the questionnaire on pig welfare perceptions

Pig welfare attributes	Pig welfare profiles										
	1	2	3	4	5	6	7	8	9	10	11
mixing unfamiliar pigs (X_1)	Yes	Yes	Yes	Yes	**No**	**No**	**No**	**No**	Yes	**No**	**No**
angle unloading bridge (X_2)	>20°	**≤20°**	**≤20°**	>20°	**≤20°**	>20°	>20°	**≤20°**	>20°	**≤20°**	**≤20°**
resting period (hours) (X_3)	2	2	**4**	**4**	**4**	**4**	2	2	2	**4**	**4**
water spraying lairage (X_4)	No	**Yes**	No	**Yes**	No	**Yes**	No	**Yes**	**Yes**	No	**Yes**
stock density (kg/m²) (X_5)	300	**235**	300	**235**	**235**	300	**235**	300	300	300	**235**
handling (X_6)	rough	rough	**gentle**	**gentle**	rough	rough	**gentle**	**gentle**	**gentle**	**gentle**	**gentle**
keep overnight (X_7)	Yes	**No**	**No**	Yes	Yes	**No**	**No**	Yes	**No**	Yes	**No**
SCORE	....	....	....	....	....	....	....	....	....	....	....
Examples:											
- expert (resp. 4)	0	50	55	54	60	49	64	65	40	66	100
- cons. (resp. 7)	0	40	55	50	20	25	80	70	65	60	100

Ordinary Least-Squares regression: $\hat{y} = C^{st} + \beta_1{*}X_1 + \beta_2{*}X_2 + \beta_3{*}X_3 + \beta_4{*}X_4 + \beta_5{*}X_5 + \beta_6{*}X_6 + \beta_7{*}X_7$, was used to break the respondent's overall pig welfare scores on the set of profiles into the contribution of each attribute level. If necessary, the resulting pig welfare regression coefficients were rescaled in such a way that the added sum per case equalled 100. Next, correction was made for the inter-stage interactions of mixing pigs in subsequent stages and the regression coefficient. Then each attribute was multiplied by the relative pig welfare contribution of the corresponding stage to obtain the chain related pig welfare regression coefficients. The latter added up to a maximum total of 100 pig welfare points.

Appendix 5.II Some technical and economic input and output in the default situation of the economic pork chain simulation model.

TECHNICAL INPUT		ECONOMIC INPUT	
Farrowing			
max. number of breedings per cycle	3	feed prices (Dfl./100 kg)	
min. duration production cycle/sow (days)	151	- sows	44.20
litter size (piglets born alive)	10.8	- piglets	66.43
piglet mortality (%)	14.5	- start feed rearing	53.60
weaning age (weeks)	4		
age at which feeder pigs are sold (weeks)	10		
Fattening			
daily growth rate (grams)	719	feed prices (Dfl./100 kg)	
standard dev. daily gain (grams)	72	- start-growing	53.6
loss rate (%)	2.1	- finishing	46.0
number of deliveries per cycle	2		
Transportation			
occupation rate (%)	90	investment truck	273,000
net total surface (m^2)	52.9	diesel (Dfl./litre)	1.1
average distance per ride (km)	175		
daily driving hours	12		
Slaughtering			
slaughter efficiency (%)	77	average return (Dfl./kg)	4.2
ratio sold as carcass: sold in parts	30:70		

TECHNICAL OUTPUT		ECONOMIC OUTPUT	
Farrowing			
number of sows present per year	165	investment/sow place	4988.5
litters/sow/year	2.29	labour costs/feeder pig sold	21.88
feeder pigs sold/sow/year	21.11	housing costs/feeder pig sold	35.14
culling rate (%)	40	interest/feeder pig sold	3.74
days lost/sow	16.64	total feed costs/feeder pig sold	39.75
number of replacement gilts present/sow	0.08	health & AI costs/feeder pig sold	5.83
occupation rate (%)	91.8	other costs/feeder pig sold	13.66
labour time/sow/year (hours)	14.2	total production costs/feeder pig sold	120.00
Fattening			
number of fattening pigs present	2023	investment/pig place	720
number of barns	2.3	labour costs/pig sold	12.31
number of production cycles/year	2.94	housing costs/pig sold	33.62
feed conversion	2.80	interest/pig sold	5.65
interval first-last delivery (days)	16.48	feed costs/pig sold	113.58
number of feeder pig suppliers	1	health costs/pig sold	3.33
occupation rate (%)	93.9	other costs/pig sold	20.19
labour time/pig sold (hours)	0.38	total production costs/pig sold	188.69
Transportation			
number of farms on which to load	2.3	transportation costs/pig	3.61
daily number of rides	2.3		
Slaughtering			
% of pigs without lesions	79	slaughtering costs/pig	44.6
labour time slaughtering/pig (minutes)	8		

Chapter 6

ECONOMIC OPTIMIZATION OF PORK PRODUCTION-MARKETING CHAINS II. MODELLING OUTCOME[1]

ABSTRACT

Static and dynamic linear programming were used to evaluate the development of pork chain concepts that take animal welfare concerns into account. Pig welfare attributes and the additional costs of production and distribution were balanced. The pig welfare perceptions of both a consumer-related respondent and a pig welfare expert served as input. Pig welfare estimations represented improvements additional to the pig welfare level in the default situation and were expressed on a relative scale from 0 to 100 points. Results showed that at relatively low levels of additional pig welfare (i.e. ≤ 20 to 30 pig welfare points), especially slaughter-house- and transportation- related attributes were incorporated into the chain concepts. Examples included the attributes 'reducing stock densities', and 'using automated unloading platforms'. Moreover, 'illumination standards' were raised in both the farrowing and fattening stage. Total additional costs ranged from Dfl. 0.56 to Dfl. 1.20 per pig from the farrowing to the slaughtering stage. Sensitivity analysis showed that the least-cost chain concepts at these low levels of additional pig welfare were very stable. The additional costs incurred increased progressively at higher levels of additional pig welfare to a total maximum (i.e. 100 welfare points), ranging from Dfl. 77 to Dfl. 114.

6.1 INTRODUCTION

In recent years animal welfare has received increased attention as being an important consumer concern. In establishing product differentiation policies in order to respond to this type of concern, animal welfare preferences and the additional cost or profitability of production have to be balanced. To date, these aspects of animal welfare - perceptions and economics - have been analysed neither extensively nor in an integrated manner. With respect to consumer concerns about pig welfare in the Netherlands, only one study is known to deal with the perception of outdoor-produced pork, and the motives and - socio-demographical - characteristics of its buyers (Steenkamp and Oude Ophuis, 1987). Although the existence of animal welfare concerns of consumers is regularly mentioned (e.g. Guither and Curtis, 1983; Barkema, 1993), the exact type of concerns, including

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perceptions and preferences has not been elaborated on. Some popular press papers (e.g. Anonymous, 1994) of animal welfare pressure groups provide some clues on those concerns and potential improvements, however. Economic considerations available especially concern quantifications of technical and economic performance of complete existing pig welfare-related systems, such as the outdoor systems (e.g. Lazarus et al., 1991; LeDenmat et al., 1994; Mortensen et al., 1994).

In a previous paper, the pig welfare perceptions of both consumer-related respondents and scientific pig welfare experts were evaluated, using a questionnaire based on conjoint analysis (Den Ouden et al., 1996b). The corresponding economic effects of the pig welfare concerns were quantified, using an economic pork chain simulation model (Den Ouden et al., 1996a). In the model a farrowing, a fattening and a slaughtering stage were included and transportation of pigs between the stages was considered. Results showed that the attributes that were considered most important with respect to pig welfare also proved to be rather expensive. Examples were group housing of sows and increasing the weaning age in the farrowing stage, supply of straw and additional floor space during fattening, and not mixing unfamiliar pigs and quiet handling of pigs during transportation and prior to slaughtering (Den Ouden et al., 1996b).

However, in designing products differentiated on the basis of pig welfare, the pork product that satisfies the highest level of pig welfare is not the only point of interest, because that product concept may also be the most expensive one. Consumers may prefer a product with less additional pig welfare guarantee at a more favourable price. Therefore, it is important to explore how pig welfare perceptions and economics are balanced. Effects of requirements of pig welfare on structure, economics and stability of pork production-marketing chain concepts will reveal useful information on establishing pig welfare policies for both government and businesses. In this paper a dynamic linear programming model is presented which deals with these issues. The optimization model is used to evaluate the development of pork production-marketing chain concepts, in which additional costs to realize increasing levels of extra pig welfare in the pork chain are minimized.

6.2 MATERIAL AND METHODS

6.2.1 General outline

An overview of the methods used is presented in Figure 6.1. The cost coefficients of the pig welfare attributes were provided by the pork chain simulation model (Den Ouden et al., 1996a) as economic output and served as economic input for the optimization models (Figure 6.1). Concerns about pig welfare were evaluated, using a questionnaire based on conjoint analysis of multi-attribute parameters (Green and Srinivasan, 1978; Hair et al., 1990). Both a static and a dynamic linear programming model were developed in order to explore the potential effects of incorporating concerns about pig welfare into the structure and economics of the pork production-marketing chain (further denoted as 'pork chain').

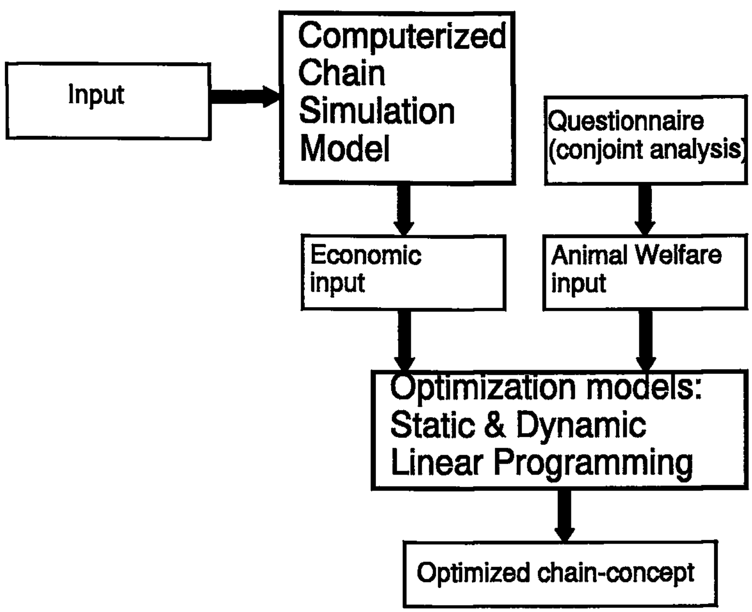

Figure 6.1 Schematic representation of the methods used in the pork chain models

Although the static approach uses considerable less computation time and provides optimized pork concepts for one-moment or new investment situations, it lacks the connection between successive calculations. Because of this, attributes can be excluded or reduced in value at increasing levels of desired additional pig welfare in the pork chain concept. If, in practice, a gradual incremental improvement in the welfare of pigs is pursued over a period of time, each time adding pig welfare improvements to an 'existing' situation, these divestments are not realistic. Therefore, in the dynamic approach an extra constraint was added to make sure that once included, attributes were at least maintained at the same levels.

6.2.2 Model input on pig welfare and costs

The questionnaire to evaluate concerns about pig welfare was developed and analysed by using conjoint analysis. Conjoint analysis is a versatile technique, widely used in consumer research, by which subjective and differently-scaled product attributes can be quantitatively evaluated on a common scale (Hair et al., 1990). Questionnaires were sent to pig welfare experts and consumer-related respondents, including retailers and members of animal welfare pressure groups.

In general, results of the questionnaire showed that the farm stages farrowing and fattening were considered most important with respect to pig welfare (Den Ouden et al., 1996b). Important attributes included group housing of non-lactating sows, supply of straw and additional floor space. The way in which the pigs were handled during transportation and prior to slaughtering and whether or not it was allowed to mix unfamiliar pigs, were regarded as most important pig welfare attributes in those two stages. Respondents were rather heterogeneous, however, with respect to the estimated individual pig welfare regression coefficients or part-worths (Den Ouden, 1996b). Individual coefficients ranged from 0.09 to 16.31 on a scale from 0 to 100. It is emphasized that the pig welfare coefficients represented estimated improvements in pig welfare *additional* to the pig welfare level in the default situation. After multivariate analysis of variance, no significant difference could be found between experts and consumer-related respondents ($p > 0.1$).

The economic effects of the pig welfare attributes were calculated by using an economic pork chain simulation model (Den Ouden et al., 1996a). As the stages of the pork chain are linked vertically, their behaviour may influence both their own technical and economic performances and that of the successive stages. Using the pork chain model rather than models simulating the separate stages of the chain, these so-called interstage relations could be taken into account. Economic effects of the pig welfare attributes were calculated on an animal basis and represented the change in net result by changing the level of the pig welfare attribute from the lowest (default), or expected least preferred, to the highest, or expected most preferred value.

The pig welfare attributes that were found to be the most expensive ones of the attributes reviewed, involved the availability of roughage, straw and additional floor space, and access to outdoor space in the fattening stage. In the other stages the attributes related to social contacts incurred the highest additional costs, including not mixing unfamiliar pigs and loading pigs on one single farm only for transportation, and increasing the weaning age of piglets. Additional costs incurred ranged from Dfl. 0.004 (reducing the stock density in the lairage rooms of the slaughterhouse) to Dfl. 28.25 (weekly supply of 7 kg of straw to fattening pigs) per pig from the farrowing to the slaughtering stage. In total, pig production and distribution costs increased by 22% to 32% when all pig welfare attributes reviewed were included in the pork chain concept. More details on the questionnaire on pig welfare preferences and on the economic analysis can be found in Den Ouden et al. (1996b).

Table 6.1 The pig welfare attributes with corresponding attribute levels (denoted Δ) and the corresponding quotients of pig welfare coefficient divided by the cost coefficient for both a consumer-related respondent (W_C/C_C) and an expert (W_E/C_E).

Pig welfare attributes	Default	Δ	W_C/C_C	W_E/C_E
Farrowing				
social contacts				
- mixing socially unfamiliar pigs at weaning	Y[1]	N[1]	0.9	6.0
- weaning age (weeks)	4	6	0.1	0.5
surroundings				
- illumination standards (lux/12 h./day)	N	20	6.0	4.0
- concrete floor space nursery (m^2)	0	4	3.1	0.5
- outdoor space (m^2/sow)	0	5/15[3]	2.9	0.4
- total floor space non-lactating (m^2)	1.1[2]	1.4[2]	2.8	-2.5
- housing in cubicles	N[4]	Y[a]	1.5	1.2
- group housing	N[4]	Y[a']	1.4	3.2
- moving at weaning	Y	N	1.0	0.6
- straw available (kg/pig/week)	0	1.4/7[3]	1.0	0.5
- total floor space nursery (m^2)	3.75	6.5	0.9	0.2
Fattening				
social contacts				
- mixing socially unfamiliar pigs start cycle	Y	N	0.9	0.5
surroundings				
- illumination standards (lux/12 hours/day)	N	20	8.3	10.6
- concrete floor space (m^2/pig place)	0	0.4	2.2	0.3
- straw available (kg/pig/week)	0	0.7/7[3]	1.7	0.4
- outdoor space (m^2/pig)	0	1.1/2.5[3]	1.3	0.4
- total floor space (m^2/pig place)	0.57	0.9	1.1	0.1
- ventilation automated	N	Y	0.6	0.4
- roughage fed (kg./pig/day)	0	(1/10)[5]/0.5[3]	0.6	0.3

[1] Y denotes Yes, N denotes No

[2] In case of individual housing (either tethered or in cubicles) or group housing of non-lactating sows, the floor space increased from 1.1 to 1.4 m^2/sow or from 2.0 to 3.0 m^2/sow respectively.

[3] Representing the highest attribute level as quantified by the consumer-related respondent and the expert respectively.

[4] In the default situation, non-lactating sows were tethered.

[5] The amount of roughage fed to hogs was quantified at one-tenth of the daily amount of concentrates.

[a-a'] Mutually exclusive attributes; sows can be housed in cubicles or in groups.

Table 6.1 Continued.

	Default	Δ	W_C/C_C	W_E/C_E
Transportation				
social contacts				
- handling	rough	quiet	76.3	81.0
- mixing socially unfamiliar pigs at loading	Y[1]	N[1]	0.7	4.5
- loading on various farms	Y	N	0.3	0.8
surroundings				
- ventilation automated	N	Y	5.5	9.4
- loading density (kg/m^2)	300	235	1.4	3.3
- interaction loading density x ventilation	-	-	3.1	7.5
Slaughtering				
social contacts				
- mixing socially unfamiliar pigs during lairage	Y	N	97.4	205.8
- handling	rough	quiet	4.1	2.3
- resting period (hours)	2	4	-77.9	101.6
surroundings				
- stay overnight	Y	N	-0.7	-0.6
- stock density (kg/m^2)	300	235	311.5	614.7
- water spraying during lairage	N	Y	26.0	45.1
- automated lifting platforms	N	Y	23.4	65.6
Interaction mixing unfamiliar pigs included:				
- farrowing x fattening		-	0.8	1.7
- farrowing x transportation/slaughtering		-	1.2	5.9
- farrowing x fattening x transport/slaughtering		-	1.0	3.0

[1] Y denotes Yes, N denotes No

Table 6.1 summarizes the pig welfare attributes considered in the questionnaire and the corresponding attribute levels. The quotient of the pig welfare coefficient divided by the cost coefficient per attribute is presented for the data of two respondents, one of whom was an expert and one a consumer-related respondent (Den Ouden et al., 1996b). The pig welfare attributes in Table 6.1 are in order of decreasing quotients of the consumer-related respondent. The quotients represent the improvements in additional pig welfare per Dutch guilder of additional costs. High quotients imply attributes which were found to have either a very large impact on the welfare of the pigs, or to improve the pigs' welfare at very low extra costs, or both. Negative quotients can result from an expected harmful effect on the pigs' welfare, or from a net negative cost effect. In the former case, the attribute will never be incorporated into a chain concept aimed at improving pig welfare. In the latter, the attribute will always be implemented because it is expected to improve the welfare of pigs and even to yield a benefit. In this way, the quotients serve as indicators for the sequence in which the attributes will be added to the chain concepts in designing animal-friendly differentiated pork products.

6.2.3 Pork chain optimization models

Cost and pig welfare coefficients are the basic ingredients of the linear programming model. The pig welfare attributes serve as decision variables. The attributes represent either interval-scaled or binary-scaled variables. With respect to the interval-scaled variables it is assumed that the improvements in pig welfare and the additional costs incurred vary proportionally with the change in the attribute level.

In general terms, the linear programming model can be described according to the following equations:

$$\text{Minimize } Z = \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{l=1}^{L} \delta_t * C_{i,l} * X_{i,l,t} \qquad (1)$$

Subject to

$$\sum_{i=1}^{I} \sum_{l=1}^{L} W_{i,l} * X_{i,l,t} \geq Wtot_t \qquad (2)$$

$$X_{i,l,t} - X_{i,l,t-1} \geq 0 \qquad (3)$$

remaining linear constraints which involve relations between attributes

$$X_{i,l,t} \geq 0 \quad i \in I_1;\ l = 1,..,L;\ t = 1,..,T \qquad (4)$$

$$X_{i,l,t} \text{ binary} \quad i \in I_2;\ l = 1,..,L;\ t = 1,..,T \qquad (5)$$

In which:

Z	=	total additional costs per pig from farrowing to processed pigmeat
$X_{i,l,t}$	=	attribute i at level l in time period t ($i = 1,..,I$; $l = 1,..,L$; $t = 1,..,T$)
$C_{i,l}$	=	additional costs of attribute i at level l ($l \geq 1$), expressed per pig, compared with the costs in the default situation, ($i = 1,..,I$; $l = 1,..,L$)
δ_t	=	discount factor in time period t ($t = 1,..,T$)
$W_{i,l}$	=	additional pig welfare of attribute i at level l ($l \geq 1$), compared with the pig welfare level in the default situation
$Wtot_t$	=	total additional pig welfare level desired in the chain concept in time period t ($Wtot = 0,..,100$; $t = 1,..,T$)
I_1	=	index set corresponding to the continuous variables
I_2	=	index set corresponding to the binary variables
I	=	index set corresponding to both continuous and binary variables
L	=	number of levels per attribute compared with default level ($L=1$ or 2)
T	=	number of periods in planning horizon

The objective of the linear programming model is to minimize the (net present value of the) additional costs incurred per pig in the pork chain concept (equation 1), under the constraint of satisfying the minimal total level of additional pig welfare (Wtot) desired (equation 2). Besides a dynamic linear programming approach, also a static version was developed. In the dynamic approach the value of attribute j in period t had to be equal to or higher than its value in period t-1 (equation 3). In the static linear programming approach, the time dimension (t) and equation (3) were excluded. Because many attributes are binary, the dynamic linear programming approach took considerably more computation time than the static approach in reaching an optimal solution. In the static linear programming model (T = 1), 28 interval-scaled or continuous variables and 37 binary variables were included. Using the dynamic linear programming approach (T > 1), the number of binary variables was multiplied by factor 'T'. However, in the static approach, optimal solutions at high desirable levels of additional pig welfare may not include all attributes that are present in the optimal solutions at lower levels. These solutions, therefore, are not suitable for a stepwise (or incremental) implementation of increasing pig welfare standards in practice. This problem was overcome by incorporating the time-dimension 't' and equation (3).

Additional constraints were formulated to take account of exclusive and 'obliged' relations between attributes or the cost coefficients. An example of an exclusive relation includes the various housing possibilities of non-lactating sows which have to be tethered (default), be housed in cubicles or in groups. Examples of 'obliged' relations are the requirement of concrete floor space when straw is supplied and the exclusion of tethered housing of sows when sows are given access to outdoor space. To account for time preference of costs, a discount factor in the dynamic modelling approach is calculated using an annual interest rate of 9%. The linear programming model has been programmed in OMP 4.0 (Beyers & Partners, Inc., 1993) and runs on a personal computer.

6.3 RESULTS

6.3.1 Static linear programming approach

The least-cost chain concepts of the static linear programming approach for different desirable levels of additional pig welfare are presented in Table 6.2. Results are shown for additional pig welfare (Wtot) levels of 10, 20, 30, 50, 70 and the maximum level of 100 points. The total additional costs incurred are expressed per pig from farrowing to slaughtering. When an improvement in additional pig welfare (Wtot) of at least 10 points was required, the coefficients of the consumer-related respondent resulted in an optimal chain concept incurring Dfl. 0.19 higher costs per pig (Table 6.2) than in the default situation, i.e. Dfl. 357 per pig from the farrowing to the slaughtering stage. Seven attributes were incorporated into this optimal concept ranging from 'not keeping pigs at the slaughterhouse overnight', 'reducing the stock density in the slaughterhouse lairage rooms from 300 to 235 kilograms of live weight per m^2' to 'increasing concrete floor space in nursery pens by 1.35 m^2' (Table 6.2). Increasing the Wtot constraint to higher levels, both values of some already included attributes were enhanced and new attributes were added.

The relatively low additional pig welfare levels were satisfied at lower additional costs per pig (Table 6.2) when using the coefficients of the expert. At a Wtot-level of 10 even a net benefit of Dfl 0.05 per pig was found. The money saved from not having to pay the compensation for pigs that stay at the slaughterhouse overnight, was the main reason for this net benefit. In the case of the expert, higher pig welfare coefficients were attached to attributes with relatively lower cost coefficients. Examples involve the attributes 'stock density' in the slaughterhouse and 'handling' during transportation. As a result, the corresponding quotients 'W/C' were also biggest (Table 6.1). As a result, it can be seen from Table 6.2 that when using the coefficients of the expert fewer attributes were needed to achieve the same level of additional pig welfare. However, the attributes that were incorporated were almost identical. Until a Wtot level of 30, the optimal chain concepts based on the expert only differ with respect to the length of the resting period prior to slaughter. As the consumer-related respondent considered an increase in this attribute not beneficial to the pigs' welfare (Table 6.1), this attribute was not included in the corresponding least-cost chain concepts at all (Table 6.2). The same holds for the increase in total floor space of non-lactating sows with respect to the expert. From a Wtot level of 50 points and higher, the difference in attributes included in the optimal chain concepts increased. Compared with the consumer-related respondent, particularly attributes related to the farrowing stage were included earlier.

Table 6.2 Results static linear programming approach: least-cost (Dfl./head) pork chain concepts at different desirable additional pig welfare levels, using the coefficients of a consumer-related respondent and an expert.

			consumer-related respondent						expert					
Overall Pig Welfare (Wtot)			10	20	30	50	70	100	10	20	30	50	70	100
Total extra costs (Dfl/head)			0.19	1.20	4.01	14.52	28.73	77.17	-0.05	0.56	1.48	5.98	26.11	114.02
Pig welfare attributes	default	stage												
stay overnight	Y	S	N	N	N	N	N	N	N	N	N	N	N	N
stock density (kg/m2/pig)	300	S	235	235	235	235	235	235	235	235	235	235	235	235
resting period (hours)	2	S	-	-	-	-	-	-	3.2	-	4	2.3	4	4
handling	rough	T	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet
water spraying during resting	N	S	Y	Y	Y	Y	Y	Y	-	-	Y	-	Y	Y
automated loading platforms	N	S	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y
automated ventilation	N	T	Y	Y	Y	Y	Y	Y	-	-	Y	Y	Y	Y
concrete floor nursery (m2)	0	F	1.35	-	2.31	2.31	2.33	4.0	-	-	-	-	2.31	4
illumination (lux/12 hours/m2)	N	H	-	20	20	20	20	20	-	20	20	20	20	20
illumination (lux/12 hours/m2)	N	F	-	20	20	20	20	20	-	-	20	-	20	20
stock density (kg/m2/pig)	300	T	-	275	235	235	235	235	-	-	250	235	235	235
handling	rough	S	-	-	quiet	quiet	quiet	quiet	-	-	-	-	quiet	quiet
tot. floor non-lactating (m2)	1.1	F	-	-	1.4	1.4	3	1.4	-	-	-	-	-	-
mixing during transportation	Y	T	-	-	N	N	N	N	-	-	-	N	N	N
mixing during resting	Y	S	-	-	N	N	N	N	-	-	-	N	N	N
concrete floor (m2/place)	0	H	-	-	0.03	0.2	0.2	0.4	-	-	-	-	-	0.4
outdoor space (m2/sow)	0	F	-	-	-	5	5	5	-	-	-	-	15	15
housing non-lactating sows	teth.	F	-	-	-	cubi.	group	group	-	-	-	group	group	group
straw supplied (kg/pig/week)	0	H	-	-	-	0.64	0.70	0.7	-	-	-	-	-	7
total floor space (m2/place)	0.57	H	-	-	-	-	0.58	0.9	-	-	-	-	-	0.9
outdoor space (m2/pig)	0	H	-	-	-	-	1.1	1.1	-	-	-	-	-	2.5
tot. floor space nursery (m2)	3.75	F	-	-	-	-	-	6.5	-	-	-	-	-	6.5
straw supplied (kg/sow/week)	0	F	-	-	-	-	-	1.4	-	-	-	-	7	7
mixing start fattening cycle	Y	H	-	-	-	-	-	N	-	-	-	-	N	N
automated ventilation	N	H	-	-	-	-	-	Y	-	-	-	-	-	Y
moving piglets at weaning	N	F	-	-	-	-	-	N	-	-	-	-	N	N
mixing at weaning	Y	F	-	-	-	-	-	N	-	-	-	N	N	N
roughage supplied (kg/pig/day)	0	H	-	-	-	-	-	(1/10)	-	-	-	-	-	3.5
loading on various farms	Y	T	-	-	-	-	-	N	-	-	-	-	N	N
weaning age (weeks)	4	F	-	-	-	-	-	6	-	-	-	-	-	6

Y = Yes, N = No, F = Farrowing, H = Hog fattening, T = Transportation, S = Slaughtering

Examples involve 'not mixing unfamiliar pigs at weaning', 'not moving piglets at weaning' and 'supply of straw to sows'. On the other hand, attributes such as 'access to outdoor space' and 'increasing total and concrete floor space' were added later. The consumer-related respondent attached more value to an increase in (concrete) floor space for improving the pigs' welfare than the expert did. As a result, the attribute 'increasing total floor space in the nursery pen', for example, was added to the optimal chain concept at a Wtot level of only 10 in the case of the consumer-related respondent versus a level of 70 in the case of the expert.

The differences in additional costs incurred between the expert and the consumer-related respondent are summarized in Figure 6.2. At a maximum Wtot level of 100 the additional costs equalled Dfl. 77.2 and Dfl. 114 per pig from the farrowing to the slaughtering stage respectively (Table 6.2). The latter higher costs resulted from the higher most preferred levels of the attributes 'outdoor space', 'straw' and 'roughage supply', as quantified by the expert. In total, the maximum extra costs accounted for approximately 22% and 32% of the total chain production costs in the default situation (Dfl. 357) respectively. In Figure 6.2, it can be seen that the additional costs incurred increase progressively at higher desirable levels of additional pig welfare (Wtot).

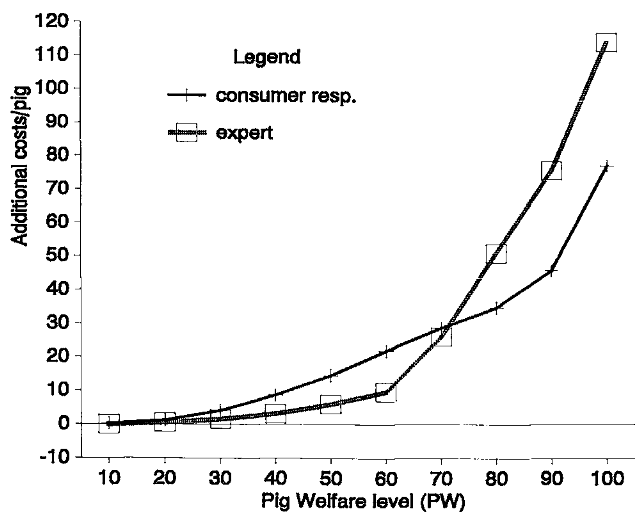

Figure 6.2 Additional chain production costs per pig at increasing levels of extra pig welfare (Wtot), using the coefficients of both an expert and a consumer-related respondent.

6.3.2 Dynamic linear programming approach

When comparing the values of the attributes of the optimal chain concepts at the various Wtot levels in Table 6.2, it can be seen that some attributes decreased or were excluded from the chain concept at a higher Wtot level. Examples are the concrete floor space of the nursery pen (Wtot level of 10 versus 20 points) in the case of the consumer-related respondent (Table 6.2), and the increase of the resting period (10 versus 20 and 30 versus 50 points), water spraying prior to slaughter and raising the illumination standards in the farrowing stage (30 versus 50 points) in the case of the expert (Table 6.2). As mentioned before, this was the main reason for switching from the static to the dynamic linear programming approach.

Results of the dynamic linear programming approach are shown for a three-step improvement in additional pig welfare (Wtot) (Table 6.3). Included are the Wtot levels at which attributes were excluded or decreased in value when using the static approach. For reasons of comparison, the total additional costs per pig rather than the discounted costs are presented.

When comparing the results of the dynamic approach (Table 6.3) with those of the static linear programming one (Table 6.2) it can be seen that indeed no attributes were excluded or decreased in value at increasing levels of Wtot. In the case of the consumer-related respondent's results, the concrete floor space in the nursery pen increased at a Wtot level of 10 as well as at 20 points. As a result of the smaller increase in concrete floor space at a Wtot level of 10 points, the attributes 'water spraying', 'automated lifting platforms' and 'automated ventilation' were no longer sufficient to satisfy the constraint of a Wtot level of 10 points. Instead, these attributes entered the optimal chain concept only at a Wtot level of 20 points. On the other hand, the illumination standards at the farrowing stage had already been raised at a Wtot level of 10 points. The attributes incorporated at the Wtot level desired in the final period influenced the optimal solutions at lower Wtot levels. As a result, as expected, the additional costs incurred at lower Wtot levels were higher in the dynamic approach than in the static one.

In the case of the expert's results, the attributes 'water spraying' and 'automated lifting platforms' at the slaughterhouse changed places as to their position at the Wtot level of 20 points. This resulted from the longer resting period which was also present at a Wtot of 20 points (dynamic approach). Moreover, the length of the resting period was reduced at the Wtot level of 30 and increased at the Wtot level of 50 in order to realize a gradual improvement (dynamic approach). Because the length of the resting period decreased and illumination standards were no longer raised at a Wtot level of 30, a further decrease of the stock density during transportation and not mixing unfamiliar pigs during transportation and resting, resulted in the least-cost additional welfare points required.

Table 6.3 Results of the dynamic linear programming approach: least-cost (Dfl./head) pork chain concepts for a desirable additional pig welfare level of 50 points in three successive steps of 10, 20 and 30 points, using the coefficients of the consumer-related respondent and the expert.

			consumer-related respondent				expert			
Overall Pig Welfare level chain (Wtot)			10	20	30	50	10	20	30	50
Total additional costs/period (Dfl/head)			0.23	0.97	2.81	10.51	-0.05	0.61	1.19	4.23
Tot. cumulative additional costs (Dfl./head)			0.23	1.20	4.01	14.52	-0.05	0.56	1.75	5.98
Pig welfare attributes	default	stage								
stay overnight	Y	S	N	N	N	N	N	N	N	N
stock density (kg/m²/pig)	300	S	235	235	235	235	235	235	235	235
resting period (hours)	2	S	-	-	-	-	3.2	3.25	3.25	3.5
handling	rough	T	quiet	quiet	quiet	quiet	quiet	quiet	quiet	quiet
concrete floor nursery pen (m²)	0	F	0.07	0.07	2.31	2.31	-	-	-	-
illumination (lux/12 hours/day)	N	F	20	20	20	20	-	-	-	-
water spraying during resting	N	S	-	Y	Y	Y	-	Y	Y	Y
automated lifting platforms	N	S	-	Y	Y	Y	-	-	-	-
automated ventilation	N	T	-	Y	Y	Y	-	-	-	Y
illumination (lux/12 hours/day)	N	H	-	20	20	20	-	20	20	20
stock density (kg/m²/pig)	300	T	-	275	235	235	-	-	235	235
handling	rough	S	-	-	quiet	quiet	-	-	-	-
tot. floor non-lactating (m²)	1.1	F	-	-	1.4	1.4	-	-	-	-
mixing during transportation	Y	T	-	-	N	N	-	-	N	N
mixing during resting	Y	S	-	-	N	N	-	-	N	N
concrete floor space (m²/place)	0	H	-	-	0.03	0.20	-	-	-	-
outdoor space (m²/sow)	0	F	-	-	-	5	-	-	-	-
housing non-lactating sows	teth.	F	-	-	-	cubi.	-	-	-	group
straw supplied (kg/hog/week)	0	H	-	-	-	0.64	-	-	-	-
mixing at weaning	Y	F	-	-	-	-	-	-	-	N

Y = Yes, N = No, F = Farrowing stage, H = Hog fattening stage, T = Transportation stage, S = Slaughtering stage

As a result of the fact that 'automated lifting platforms' were replaced by 'water spraying' in the least-cost chain concepts, the length of the resting period was slightly increased compared with the results of the static approach in order to satisfy the desired 50 extra welfare points. As a result of these changes, the total additional costs incurred at the various intermediate Wtot levels slightly increased, compared with the results of the static linear programming approach.

6.3.3 Sensitivity analysis

To gain insight into the stability of the least-cost chain concepts presented in the earlier sections, a sensitivity analysis was conducted, using the coefficients of the consumer-related respondent. The sensitivity analysis concerns the results of the static linear programming approach presented in Table 6.2. Sensitivity analysis of the optimal least-cost chain concepts was conducted by varying the ratio of the pig welfare coefficient and the cost coefficient per attribute, keeping the coefficients of the other attributes unchanged. The minimum multiplication factors or threshold values above which an attribute is excluded from or below which an attribute will be included in the optimal chain concept at the corresponding Wtot levels were calculated and are presented in Table 6.4. Threshold values varied from 1 to a maximum of 10 in order to evaluate at which value attributes would be excluded from the chain concepts. Similarly, they ranged from 1 to 0.1 to investigate the sensitivity of attributes that originally were not included in the optimal chain concepts at the corresponding Wtot levels.

In Table 6.4 the results are shown for some stable and less stable attributes (Table 6.2). In general, the higher the cost coefficient, the lower the threshold value at which the attribute is either included in or excluded from the optimal chain concept, and hence, the more unstable these attributes are. Moreover, the columns in Table 6.4 show that, on average, attributes that were added to the chain concepts at higher levels of Wtot are less stable. For example, the cost coefficient of the attribute 'access to outdoor space during fattening' had to decrease to less than 10% and 40% of the original value (Dfl. 12.38) to be included in the least-cost chain concept at Wtot levels of 10 and 30 points respectively. On the other hand, it had to increase to more than factor 1.2 to be excluded from the optimal chain concept at a Wtot level of 70 points (Table 6.4). In contrast, the transportation and slaughtering attributes that were incorporated first proved to be quite stable, as their cost coefficients had to be multiplied more than tenfold to cause the attributes to be excluded from the chain concepts.

Table 6.4 Threshold values of additional costs above which attributes are excluded from (> 1) or below which attributes are included (< 1) in the chain concepts, based on the coefficients of the consumer-related respondent (Table 6.2).

				Overall Pig Welfare level Chain (Wtot)		
Pig welfare attributes	default	stage	costs	10	30	70
stay overnight	Y	S[1]	-0.14	-0.2[2]	-0.2[2]	-0.3[2]
stock density (kg/m²/pig)	300	S	0.004	>10	>10	>10
handling	rough	T	0.08	5	>10	>10
water spraying during resting	N	S	0.036	1.9	>10	>10
automated lifting platforms	N	S	0.04	1.8	>10	>10
illumination (lux/12 hours/m²)	N	H	0.79	0.5	6	6
illumination (lux/12 hours/m²)	N	F	0.42	0.9	5	5
tot. floor non-lactating (m²)	1.1	F	0.84	0.9	1.2	1.6
concrete floor space (m²/place)	0	H	1.95	0.8	2	3
housing non-lactating sows	teth.	F	2.16	0.2	0.5	1.7
outdoor space (m²/pig)	0	H	12.38	<0.1	0.4	1.2
mixing at weaning	Y	F	1.39	0.2	0.2	0.3
roughage supplied (kg/pig/day)	0	H	9.39	<0.1	0.2	0.4
loading on various farms	Y	T	3.21	<0.1	0.5	0.6
weaning age (weeks)	4	F	8.76	<0.1	<0.1	<0.1

[1] F = Farrowing stage, H = Hog fattening stage, T = Transportation stage, S = Slaughtering stage

[2] Representing the multiplication factor above which this attribute is excluded from the optimal least-cost chain concept at the corresponding Wtot.

6.3.4 Distribution of costs and pig welfare contributions over stages

It was shown that at increasing levels of desirable additional pig welfare, the additional costs incurred per pig from the farrowing to the slaughtering stage increased progressively to a maximum of 22% to 32% of the total chain production costs in the default situation (Dfl. 357). Certain segments of consumers may be willing to pay a premium for these products. With the pork chain simulation models, it can be calculated how the additional costs incurred are distributed over the stages of the chain. This may indicate a way of redistributing a potential consumer premium back over the stages. Table 6.5 presents an example of the distribution of costs for satisfying desirable additional pig welfare levels of 10, 50 and 100 points respectively. The results are based on the coefficients of both the expert and the consumer-related respondent.

As can be seen in Table 6.5 the additional costs are unequally distributed over the stages of the pork chain. At a Wtot level of 10 points the slaughtering stage even yielded an economic benefit (of -59% of extra costs of Dfl. 0.23 per pig), whereas the farrowing and transportation stages incurred additional costs. Moreover, it was found that the share in additional costs does not always correspond with an equally important share in additional pig welfare contribution. For example, at a Wtot level of 10, the slaughtering stage not only incurred a benefit instead of a loss, but also contributed the least to the improvement of the pigs' welfare (only 13%). As the Wtot levels increased, the farm stages farrowing and fattening incurred increasingly bigger parts of both the additional costs and pig welfare improvement. Moreover, one has to realize that the various shares of the stages in the total additional costs incurred in the chain imply different increases with respect to the default production costs. For example, whereas the 49% share in total additional chain costs at a Wtot level of 50 points means an increase of approximately 4% in total fattening costs, the 9% share of the transportation stage implies a cost increase of more than 36% relative to the transportation costs per pig in the default situation.

Table 6.5 Relative distribution of the total additional costs at Wtot levels of 10, 50 and 100 points over the stages of the pork chain, using both the coefficients of the expert and the consumer-related respondent (dynamic approach).

Respondent	Pig Welfare level (Wtot)	Farrowing	Fattening	Transportation	Slaughtering	Total additional costs (Dfl/pig)
consumer-related	10	124%	-	35%	-59%	0.23 (100%)
	50	33%	49%	9%	9%	14.52 (100%)
	100	34%	59%	4%	3%	77.17 (100%)
expert	10	-	-	-173%	273%	-0.05 (100%)
	50	61%	11%	22%	6%	5.98 (100%)
	100	27%	68%	3%	2%	114.02 (100%)

6.4 DISCUSSION AND CONCLUSIONS

Static and dynamic linear programming models were developed in order to explore the potential effects of incorporating various pig welfare-related attributes into the structure and economics of the production and transportation stages of the pork chain. Although the pig welfare coefficients of the consumer-related respondent and the expert were not similar, and can only be perceived as individual perceptions, the sequence in which the various attributes entered into the chain concepts showed great resemblance. Until a Wtot level of 20 points (consumer-related respondent) and 30 points (expert), the same 9 out of 10 attributes were included in the least-cost chain concepts. These attributes involved transportation- and slaughterhouse-related attributes in particular, including 'reducing stock densities', 'water spraying in lairage rooms', 'using automated lifting platforms for unloading pigs at the slaughterhouse', and 'handling the pigs quietly without the use of electric prodders'. Moreover, illumination standards were raised in both the farrowing and the fattening stage. These attributes also proved to be quite stable in sensitivity analyses. The additional costs incurred varied between Dfl. 0.56 and Dfl. 1.20 per pig depending on the pig welfare perceptions of the respondent that were used as input.

Raising the desirable levels of additional pig welfare, the additional least-cost incurred increased progressively to a total maximum ranging from Dfl. 77 to Dfl. 114 per pig. Rather expensive farm attributes including the supply of roughage, straw and allowing animals access to outdoor space were only added to the least-cost chain concepts at high levels of additional pig welfare. Costs calculations were based on new investments. However, costs incurred to adjust an existing farming system to new requirements may differ. Results of the dynamic linear programming approach therefore cannot simply be compared with those of the static one. Applying the static results to dynamic evaluation over time would imply the consideration of divestments or accelerated depreciation times of attributes that are excluded from the optimal chain concepts at increasing levels of pig welfare. Future research should also consider this type of adjustment costs in economic evaluations, especially when it concerns pork end-products with short life cycles. Concerning strategic issues including government or business long-term policies, however, cost based on investments is the appropriate standard.

Certain consumers may be willing to pay a premium for differentiated pork products. Steenkamp and Oude Ophuis (1987) reported that consumers of outdoor-produced pork would accept a premium of Dfl. 1 to Dfl. 2 per kilogram of meat. However, usually only for the more valuable parts of the carcass such a premium is received. Assuming that 50% of all meat produced is rewarded in this way, the average total premium would lie between Dfl. 42 to Dfl. 83. However, the segment of consumers that is willing to pay this extra money may not be big. Currently, the segment of consumers that buys outdoor-produced pork is estimated at only 2% of all consumers in the Netherlands buying fresh pork. However, more consumers may be willing to buy other types of animal friendly produced pork at lower prices. Besides scale effects on production, organization and coordination costs, also costs of advertising and other types of marketing and promotion have to be taken into account. Moreover, potential positive or negative effects of these production systems on technical and economic performance have not been considered yet (Den Ouden et al., 1996b). Research therefore should be extended to include segmentation of real buyers and estimation of market shares and prices. Moreover, a redistribution mechanism has to be chosen to redistribute a potential premium back over the stages of the pork chain. As shown, the total additional costs incurred were distributed unequally over the stages of the chain and represented also varying increases in the costs of producing the standard pork product.

In general, the results of this study make a first contribution to the establishment of pork differentiation policies in order to respond to pig welfare concerns. The approach is general enough to focus on other characteristics also, such as animal health and related food safety issues. The results can be used to add to further evaluations of consumer preferences of pork products to include buyer characteristics and other relevant product attributes besides animal welfare, such as price levels and environmental characteristics.

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Chapter 7

MULTIPLE-CRITERIA DECISION MAKING IN PIG FARMING INCLUDING ECONOMIC, ANIMAL WELFARE AND ENVIRONMENTAL ISSUES[1]

ABSTRACT

An economic pork chain simulation model was used to estimate the effects of various measures aimed at either improving pigs' welfare or reducing environmental pollution on economics, nitrogen and phosphorus emissions, and on energy consumption. Pig welfare preferences were assessed by a questionnaire based on conjoint analysis. Using linear programming, least-cost pig farming concepts were designed, meeting increasingly higher targets for the level of additional pig welfare or the reduction of nitrogen or phosphorus emission. The environmental and pig welfare measures studied were found to increase farrow-to-finish production costs by 1% to 22%. Both pig welfare and environmental measures increased energy consumption. Similar conflicts were found regarding pig welfare and environmental effects of measures, such as increasing total indoor or outdoor space per pig. Using compromise programming, simultaneous optimization of pig welfare improvement, emission reduction and profitability proved to change the sequence in which measures were incorporated in the least-cost pig farming concepts. Shifting importance from environmental targets to animal welfare targets, a concurrent improvement of both criteria was found until 45% of the pig welfare target was met. After this level, animal welfare improved at the cost of the environmental criteria. At maximum improvement of pig welfare and emission reduction, farrow-to-finish costs per pig increased by 39%.

7.1 INTRODUCTION

In many regions throughout the world the scale of pig farming has increased from small to industrial. This has implications for both the way in which pigs are kept and the environment of pig production (Conway, 1990). Increasing numbers of animals are kept in considerably smaller confinements (Fraser and Broom, 1990) and the reduction of traditionally mixed farms has caused environmental problems (Conway, 1990). Main causal factors of farm environmental pollution include emissions of nitrogen oxides and ammonia (Erisman and Heij, 1991) and leaching of phosphate (Leneman et al., 1993). According to Groot Koerkamp et al. (1990) animal production accounts for 94% of total

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ammonia emissions in the Netherlands. Although pig production contributes only half as much as dairy farming, it still accounts for 30%, while the remaining 10% comes from poultry production. Public concern about animal welfare (Harrison, 1964; Guither and Curtis, 1983; Ekesbo, 1992) and environmental pollution (Carson, 1963; Conway, 1990) has been known for a long time. In several countries this has led to the development of special legislation and guidelines (Ekesbo, 1992; Hacker and Du, 1993). On the other hand public interest of this type has created opportunities for selecting market segments to which more value can be offered through product differentiation. An example is the 'outdoor'- or 'free range'-produced pork sold in the marketplace.

Various on-farm measures are available in order to reduce environmental pollution and improve animal welfare. Environmental measures include adaptions of animal feeds, feed regimes, and animal housing (Leneman et al., 1993). Housing facilities are also considered to affect animal welfare (Fraser and Broom, 1990). Examples include the amount of indoor and outdoor floor space per animal and loose or restricted housing systems (Ekesbo, 1992). Many of these measures require high investments from farmers (Lazarus et al., 1991; Leneman et al., 1993; Den Ouden et al.; 1996a). Besides a tense relation of these measures with profitability, some authors mention conflicts between pig welfare and environmental measures (Verdoes, 1990; Ekesbo, 1992). So far, integrated research including pig welfare, environmental pollution and economics has been slender. This paper intends to make a contribution in this respect. Based on the literature, results of a questionnaire on pig welfare issues, and an economic pork chain simulation model, it summarizes and estimates effects of various pig welfare and environmental measures both separately and in relation to each other. Results apply to the production of feeder pigs and fattened pigs and the economics of feeder pig transportation in between these production stages. Using linear programming, it was found that production costs increased by about 1 to 22% if constraints on either phosphorus (P) or nitrogen (N) emission or extra pig welfare were increased. Measures aimed at improving pig welfare or reducing N- or P-emission were found to increase energy consumption. Similar conflicts were found regarding pig welfare and environmental effects of measures, such as increasing total indoor or outdoor space per pig. Multiple-criteria decision making techniques (Romero and Rehman, 1989) were used to analyse the effects of balancing the relative importance of pig welfare, environmental pollution and profitability simultaneously. Shifting importance from environmental targets to animal welfare targets, simultaneous optimization showed a concurrent development of emission reduction and pig welfare improvement until 45% of the pig welfare target was met. After this level, animal welfare improved at the cost of the environmental criteria. When the pig welfare target was reached, farrow-to-finish costs per pig had increased by 39% and N- and P-emission reductions were at 64% and 97% of their targets respectively.

7.2 MATERIAL AND METHODS

7.2.1 General outline

Figure 7.1 presents an overview of the major materials and methods used. Central to the approach are two mathematical models: a simulation model and an optimization model. An economic pork chain simulation model (Den Ouden, 1996c) was used to calculate the economic effects of both the pig welfare and environmental measures. Furthermore, environmental effects in terms of nitrogen (N) and phosphorus (P) emissions and effects on energy consumption were calculated. The pig welfare coefficients were estimated from a questionnaire based on conjoint analysis of multi-attribute parameters (Den Ouden et al., 1996a). Data on the environmental criteria were based mainly on Leneman et al. (1993). Together with the pig welfare coefficients, the economic and environmental output formed the input for the compromise programming model. Both the simulation and the optimization model run on a personal computer.

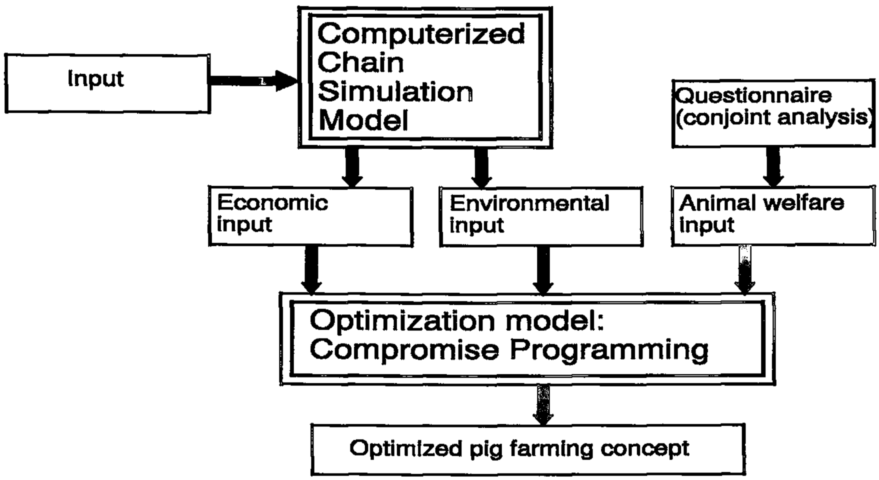

Figure 7.1 Schematic representation of the materials and methods used

7.2.2 Base farm situation

Technical and economic in- and output of the base pig farrowing and pig fattening farm situation is presented in Appendix 7.I. Pig farrowing and fattening are performed at separate pig farm operations. At a live weight of approximately 23 kg, feeder pigs have to be transported from the farrowing farm to the fattening farm. On the latter, they are grown and finished to a live weight of about 110 kg, at which weight the fattened pigs are transported to a slaughterhouse. Fattening pigs are fed a starter and a finishing feed, while sows are fed with one complete sow diet. The feeding activity of pigs is fully mechanized, saving considerable labour time. As a result the farm size per full-time equivalent (f.t.e.) was calculated to be approximately 165 sows and 2000 fattening pigs on average present on the farrowing and the fattening farm respectively. Including an input value of 28 lactation days, the minimal length of a farrowing cycle equals 151 days (Appendix 7.I). However, as a result of days lost due to failure to conceive after (re)breedings, the average cycle length was calculated to be approximately 160 days. Combined with the input on the average litter size and piglet mortality, this implied that 2.29 litters were produced and 21.1 feeder pigs were sold per sow per year (Appendix 7.I). Input on housing facilities was assumed to represent minimal floor surfaces and maximal slatted floor rates (Appendix 7.I). Regarding pig fattening, average daily gain is assumed to equal 719 grams. Fattened pigs are sold in 2 deliveries. Because the all-in-all-out system is applied, a new cycle can start only after the last delivery from a fattening room. Based on these assumptions, 2.94 fattening cycles per year were calculated.

In the base situation, the intake of N and P via feed consumption was assumed to range from 25.6 (sow feed) to 29.1 (piglet feed) grams of N and from 5.0 (finishers) to 6.7 (piglet feed) grams of P per kg of feed intake (Appendix 7.I). Output included an N- and P-excretion of 1.5 and 0.4 kg per feeder pig sold and 4.5 and 0.8 kg per fattened pig sold respectively. Based on the relatively small floor spaces but high slatted floor ratios, N-volatilization was assumed to equal 8.1 and 3.8 kg per sow and fattening pig place per year respectively (Appendix 7.I). As a result, the ratio of N-volatilization from the barn versus N-excretion was calculated to be 0.21 on the farrowing farm and 0.17 on the fattening farm. Furthermore, output showed an N-leaching of 145 and 240 kg per hectare on the farrowing and the fattening farm respectively. P-leaching amounted to approximately 80 kg per hectare on the farrowing farm and 100 kg per hectare on the fattening farm. These results are in line with Leneman et al. (1993) and Wijnands et al. (1988). Total consumption of energy per fattened pig sold was almost 3.5 times higher than the energy consumption per feeder pig.

In total, the default production costs were US$ 72.7 per feeder pig sold and US$ 114.4 per fattened pig sold (excluding the price for the purchase of feeder pigs). Thus, the integrated farrow-to-finish cost equalled US$ 187.1 (Appendix 7.I). In the farrowing, and especially in the fattening stage, feed costs made up the biggest part of total production costs. Due to governmental regulations Dutch farmers have to pay a levy for each kg of P_2O_5 produced in excess of an amount of 125 kg per hectare (Hacker and Du, 1993). Manure that cannot be applied to the farmland is removed from the farm at a cost of US$ 10.6 and US$ 9.1 per m^3 of sow and fattening pig manure respectively (Appendix 7.I). In total, the manure levy and disposal costs equalled US$ 2.3 per feeder pig sold and US$ 3.8 per fattening pig sold (Appendix 7.I).

7.2.3 Model input on environmental criteria and corresponding economics

Environmental concept and input

Three sources of environmental imposition were considered: nitrogen (N) emission, phosphorus (P) emission and energy consumption. Figure 7.2 shows a schematic representation of the nitrogen flow on farms. The flow starts with the pigs receiving N via the dietary protein of the feed which is used for growth, production of piglets etc. The part of the dietary N that is not retained in the animal is excreted via faeces and urine, collectively called 'manure'. Each time manure comes into contact with air, ammonia (NH_3) is formed and volatilizes. This means that volatilization will take place in the barn, during manure storage outside the barn and during and after application of manure to the farmland. The level of ammonia volatilization in the barn is affected by, among other variables, housing conditions, such as pen and floor type and amount of slatted floor space (Verdoes, 1990).

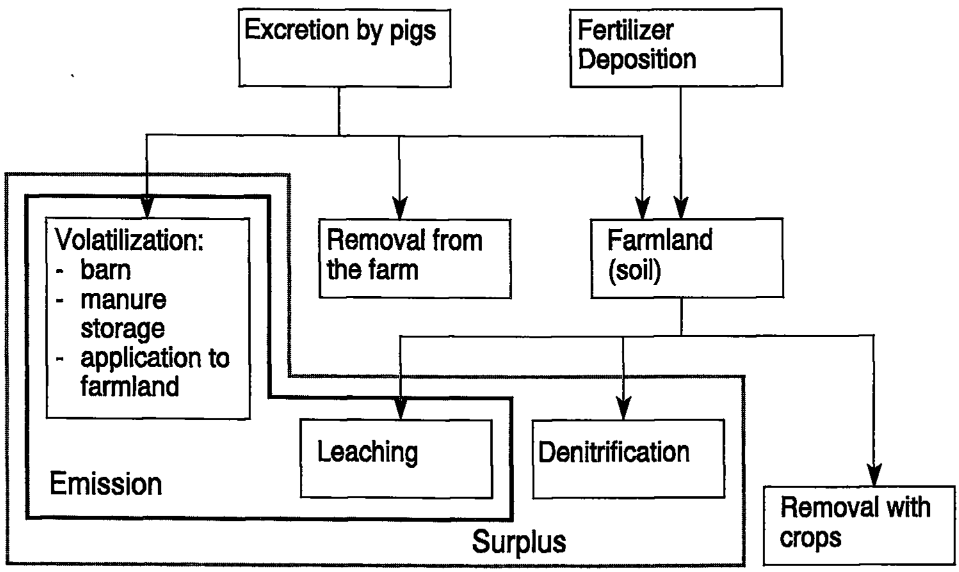

Figure 7.2 Nitrogen flow on farms

Because in the Netherlands the period during which manure may be applied to farmland is limited by government regulations, manure is stored either under the slatted floors in the barn or outside the barn in silos, or both. In 1992, a maximum of 250 kg of manure-phosphate was allowed to be applied per hectare to provide minerals for growing silage corn. The rest of the pig manure must be removed from the farms, and either be transported to manure processing plants or to farms which had not yet reached the limit of applicable manure.

Besides manure, fertilizer and deposition are two other sources of N input to the soil. The N that is not used by the crops, remains in the soil where it leaches (60%) or denitrificates (40%). It is assumed that in the soil N-mineralization and N-accumulation are in balance with one another. The difference between N-input via animals, fertilizer and deposition, and N-output via removal from the farm or with the crops, is called the N-surplus. N-emission is defined as the sum of N-volatilization and N-leaching, expressed in kg of N. The phosphorus (P) flow on pig farms is similar to the N flow. However, compared with Figure 7.2, no volatilization or denitrification occurs. The P not used by crops is called the P-surplus and can be divided into P-accumulation and P-leaching. Complete phosphorus saturation of the soil is assumed. P-emission is defined as P-leaching, expressed in kg of P.

With respect to energy consumption, direct and indirect energy use are distinguished. Direct energy consumption refers to the amount of energy supplied by the energy carriers gas, electricity and oil including diesel. Indirect energy use refers to the level of energy needed to produce all material and immaterial input of the farm, such as animals and feed bought, and buildings. Total input of energy is represented as the GER-value (Gross Energy Requirement), expressed in MJ. The GER-values of the various energy carriers and inputs of livestock farms were calculated by Brand and Melman (1993) (Appendix 7.I).

Measures to reduce N- and P-emissions

Table 7.1 presents several measures to reduce emissions on pig farms. The effects on production costs, N-emission, P-emission and on total energy consumption per animal sold are presented. Effects shown are expressed relative to the base values. The various measures are summarized under three main headings: feeding measures, farm measures and industrial processing of manure. The ratio between N-excretion and N-volatilization from the barn and between amount of N in the manure and N-volatilization from the silo are assumed to remain constant. Furthermore, it is assumed that the performance of the pigs is not affected by the emission reduction measures.

Table 7.1 Various emission reduction measures and their effects on total production costs per animal (US$/head) and on N- and P-emissions (%), and on total energy used (%). The effects are presented as deviations from the default situation.

	Farrowing					Fattening				
	N-emission				Costs	N-emission				Costs
	Volatil.	Leaching	P-emission	Total energy	(US$/ head)	Volatil.	Leaching	P-emission	Total energy	(US$/ head)
Default (grams or MJ per head)	384.7	151.8	86.9	755.5	72.7	947.0	519.2	215.5	2607.7	114.4
Feeding measures										
a Multiple-stage feeding (MSF)	-8.8	-11.1	-2.5	0.0	+0.1	-3.3	-3.9	-11.8	-	-0.9
b MSF & protein restriction	-18.0	-20.5	-2.5	0.0	+0.6	-16.1	-19.3	-11.8	-	-2.4
c MSF & ↓ P-safety margin	-8.8	-11.1	-15.2	0.0	+1.0	-3.3	-3.9	-24.3	-	-1.0
d MSF & phytase	-8.8	-11.1	-31.3	0.0	+0.2	-3.3	-3.9	-33.8	-	-0.7
Farm measures										
e Housing adjustments (small)	-12.1	+5.1	-	+0.1	+0.1	-19.3	+6.2	-	+0.3	+1.4
f Housing adjustments (big)	-52.5	+21.9	-	+8.4	+5.7	-38.5	+12.3	-	+5.5	+7.4
g Air cleaning	-67.8	-	-	+6.0	+2.9	-64.8	-	-	+5.0	+8.3
h Manure storage with roof	-11.8	+4.9	-	+0.2	+0.4	-14.6	+4.6	-	+0	+0.4
Industrial manure processing (i)	-1.6	-65.5	-89.4	+0.2	+0.9	-2.1	-72.6	-87.2	+0.2	+1.7
Packages										
b+e+h	-38.0	-14.5	-2.5			-45.1	-15.4	-11.8		
b+f+h	-72.4	-0.2	-2.5			-61.9	-4.6	-11.8		
b+f+h+i	-74.0	-65.5	-90.1			-64.0	-73.3	-90.0		
b+g+h	-83.3	-18.1	-2.5			-82.7	-10.0	-11.8		
a+g+i	-72.1	-67.2	-90.1			-68.0	-73.2	-90.0		
c+i	-10.3	-67.2	-93.1			-5.3	-73.2	-93.0		
d+i	-10.3	-67.2	-96.7			-5.3	-73.2	-95.0		

Feeding measures are focused on reducing the intake of N and P via the diet. The altered N- and P-levels of the various feeds are presented in Appendix 7.II. As the intake decreases, so does excretion of N and P in manure. Consequently, N-volatilization and N- and P-leaching will decrease as well. Increasing the number of different rations fed to an animal, the so-called 'multiple-stage feeding', makes it possible to better adapt the feed ration to the specific N and P needs of the animal. As a result, N-volatilization, N-leaching and P-leaching were reduced by 9%, 11% and 3% respectively in the farrowing stage and by 3%, 4% and 12% respectively in the fattening stage (Table 7.1). Combining multiple-stage feeding with a further restricting of the N- or P-levels of the rations, the emissions decreased even further. The enzyme phytase enables the animal to better utilize the dietary phosphorus, resulting in an approximately 30% reduction in total P-emission per pig sold (Table 7.1). Extra costs of producing and distributing more rations were assumed to amount to US$ 0.3 per 100 kg. In total, the larger amount of cheaper finishing feed caused the total feed costs per fattened pig to decrease. Compared with the standard one sow-diet, non-lactating sow feed was cheaper whereas lactation feed was more expensive. As a result, production costs per feeder pig sold increased.

The farm measures are aimed at reducing the N-volatilization from the barns, from the air expelled from the barns, or from the manure storage outside the barn (Appendix 7.II). As a result, more N remained in the manure that was transported to the silo outside the barn and applied to the farmland. Small housing adjustments refer to adaptions of the floor types. Big housing adjustments include the implementation of a sewer and flushing system in the barns (Hoste and Baltussen, 1993). Air cleaning systems do not influence the N-volatilization from the manure in the barn, but remove ammonia from the air expelled from the barn by transporting the air through a cleaning medium (Verdoes, 1990). Big housing adjustments and the air cleaning system had the biggest effects on N-volatilization. In total, reductions varied from 38.5% to 67.8% (Table 7.1). However, these measures also incurred the highest additional costs per animal. Besides heavy investments in buildings and equipment, extra costs of water and energy were incurred as well.

In the case of industrial processing of manure, the amount of manure-P applied to farmland was limited to 90 kg. Instead, more N-fertilizer was used. N- and P-leaching were reduced considerably by 65% to about 90% (Table 7.1). The extra costs incurred by the manure processing option mainly consisted of manure removal costs (Appendix 7.I).

When calculating the combined effects of various measures on N- and P-emissions, it became clear that the individual effects cannot simply be added up linearly. In general, emission reductions realized by packages of measures were lower than the sum of the individual effects. This did not hold for the effects on energy consumption and economics. Moreover, because the inclusion of the considerable effects of the feeding measures or manure processing, all packages shown reduced both N-volatilization and N-leaching.

Similar to the effects of the individual measures, the packages including big housing adjustments, air cleaning and/or manure processing had the biggest impact on the emissions.

7.2.4 Model input on pig welfare

Pig welfare questionnaire

Animal welfare issues have become of increasing interest to consumers (Guither and Curtis, 1983; Ekesbo, 1992). Although the animal welfare implications of various pig husbandry systems can be assessed by using scientific indicators, it is difficult to use and evaluate these indicators simultaneously (Smidt, 1983; Den Ouden et al., 1996a). That is why a questionnaire based on conjoint analysis of multi-attribute parameters (Hair et al., 1990) was used to estimate pig welfare perceptions. In the questionnaire, alternative combinations of pig welfare variables had to be judged on an interval scale ranging from 0 to 100. Questionnaires were completed by pig welfare experts and so-called consumer-related respondents, i.e. people working in retail or in animal welfare advocacy groups (Den Ouden et al., 1996a and 1996b). Ordinary least squares regression analysis was used to determine the contribution of each variable to the respondent's overall judgements. Pearson's product moment correlation coefficient and Kendall's τ rank correlation coefficient (Siegel, 1956) were used to test both the internal and predictive validity.

The pig welfare variables considered are presented in Table 7.2. Per variable, both the base value and the alternative value aimed at improving pigs' welfare ('Δ') are shown. The variables refer to various pig farming practices including housing facilities, feeds supplied and other husbandry issues. Examples concerning housing facilities involve the amount of total floor space, the share of concrete floor space, loose or restricted housing conditions of non-lactating sows, whether or not animals have access to outdoor space, and illumination standards. In general, more (concrete) floor space, more freedom of movement and the ability to have social contacts are considered beneficial to pigs' welfare (Ekesbo, 1992). Supply of straw and roughage provides distraction and has food functions. Other husbandry items concern the weaning age of piglets and whether or not unfamiliar pigs are regrouped after weaning or at the start of the fattening cycle. Mixing may increase fighting behaviour to re-establish a new social rank and is therefore considered harmful to pigs' welfare. More background information on the effects of these variables on pigs' welfare can be found in Den Ouden et al. (1996a) and Fraser and Broom (1990).

In analysing the questionnaire results, the average Pearson's r and Kendall's τ were found to be higher than 0.8, indicating fairly good fits of the additive models to the data. In general, housing conditions including group housing of non-lactating sows, supply of straw to fattening pigs and amount of total and concrete floor space were regarded as most important with respect to pigs' welfare. The data of one consumer-related respondent were selected for further use in this paper (Table 7.2). The corresponding models assessed were all significant ($p < 0.001$) and scored the highest internal and external validities (r and $\tau > 0.95$). The data in Table 7.2 show a particularly high preference for 'access to outdoor space'. The pig welfare regression coefficients of the consumer-related respondent equalled 5.69 and 16.31 in the farrowing and fattening case respectively (Table 7.2). Next to outdoor space, supply of straw to fattening pigs (10.18), the amount of floor space (8.64) and group housing of non-lactating sows (3.92) were considered most important with respect to pigs' welfare. This was in correspondence with the average perception of the respondents. Results of the pig welfare questionnaire have been described in more detail in Den Ouden et al. (1996a).

Economic and environmental effects of pig welfare variables

The economic effects of the pig welfare variables are presented in Table 7.2. They are expressed in U.S. Dollars per animal sold at an exchange rate of 1.65 Dutch guilders per 1 U.S. Dollar. The cost estimates represent the additional costs incurred when changing from the base value to the alternative value. Farm size was assumed to be constant.

With respect to the farrowing farm, the highest additional costs per feeder pig sold were incurred if the weaning age was changed from 4 to 6 weeks. The main cause of this cost increase was the considerable decline in production efficiency, as only 2.1 instead of 2.29 litters were produced per sow per year. In total, production costs per feeder pig sold increased by US$ 5.31 (Table 7.2). When sows were fed a non-lactation and a lactation feed instead of one sow diet, the higher amount of more expensive lactation feed caused the additional costs to be even higher, i.e. US$ 5.5 per feeder pig sold. The extra costs included extra transportation costs because smaller batches of feeder pigs were transported to the fattening farm weekly. Smaller batches also caused the number of feeder pig suppliers per fattening room to increase from 1 to 2. Elbers (1991) found that an increasing number of feeder pig suppliers were associated with higher drug use, higher mortality rates, lower daily gain and higher levels of pathological lesions at slaughter. Including these findings, additional costs of 2 instead of 1 feeder pig supplier of US$ 2.25 per fattened pig sold were incurred (Table 7.2). Moreover, due to the smaller number of pigs sold per year, the additional costs of other variables increased as well with an increased weaning age of piglets. Combining delayed weaning with the variable 'not moving piglets from nursery pens to rearing pens' was an exception. Because the number of expensive nursery pens had already increased to allow piglets to be weaned at 6 instead of 4 weeks of age, total extra production costs were 'only' US$ 5.6 in this combination. Similar interaction effects on costs were calculated for other variables. For example, as the illumination standards were measured in lux per m^2 per 12 hours per day, more space per animal also caused the illumination costs to increase. In Table 7.2 maximum illumination costs are presented.

Table 7.2 The pig welfare variables with corresponding value levels (denoted Δ), pig welfare coefficients, additional costs per animal, additional effect on farm income, and the additional effects on N-emission (%), P-emission (%) and total energy use (%).

			Welfare	Costs (US$/ head)	N-emission Volatil.	N-emission Leaching	P-emission	energy
Farrowing	***Base***	**Δ**						
Default (grams or MJ/head)			0	72.73	384.7	151.8	86.9	755.5
- outdoor space (m^2/sow)	0	5	5.69	1.20	+29.9	-12.5	-	+0.4
- group housing[2]	N[1]	Y[1]	3.92	1.68	+10.6	-4.4	-	+0.4
- housing in cubicles[2]	N	Y	3.15	1.31	-	-	-	+0.6
- straw (kg/pig/week)	0	1.4	3.05	1.94	-	-	-	-4.3
- tot. space group (m^2)	2.0	3.0	2.35	0.51	+10.6	-4.4	-	+0.3
- illumination (lux/12 h./d)	N	20	2.54	0.25	-	-	-	+2.3
- moving at weaning	Y	N	2.15	1.27	-	-	-	+0.9
- tot. space nursery (m^2)	3.75	6.5	2.12	1.45	+10.6	-4.4	-	+0.7
- mixing pigs at weaning	Y	N	1.29	0.58	+0.5	-0.3	-	+0.3
- concrete space nursery (m^2)	0	4	1.06	0.21	-4.8	+2.0	-	+0.1
- weaning age (weeks)	4	6	1.00	5.31	+8.0	+1.6	+3.9	+6.8
- tot. space indiv. (m^2)	1.1	1.4	0.71	0.15	+2.9	-1.1	-	+0.1
Fattening	***Base***	**Δ**						
Default (grams or MJ/head)			0	114.36	947.0	519.2	215.5	2607.7
- outdoor space (m^2/pig)	0	1.1	16.31	+4.92	+63.8	-20.5	-	+0.5
, longitudinal vs. cross-sectional				+2.58	-	-	-	+0.3
- straw (kg/pig/week)	0	0.7	10.18	+3.56	-	-	-	-0.2
- total space (m^2/pig place)	0.57	0.9	8.64					
. cross-sectional				+4.90	+38.0	-12.2	-	+0.7
. longitudinal				+3.21	+38.0	-12.2	-	+0.5
- illumination (lux/12 h./d)	N	20	6.55	+0.48	-	-	-	+1.2
- roughage (kg/pig/dag)	0	(1/10)[3]	5.16	+5.69	-	-	-	+0.8
- concrete space (m^2/place)	0	0.4	4.32	+1.18	-17.3	+5.5	-	+0.2
- mixing pigs start cycle	Y	N	3.21	+1.67	+0.2	-0.1	-	+0.2
- ventilation automated	N	Y	0.98	+0.95	-	-	-	+0.1
- no. of feeder pig suppliers[4]	1	2	-	+2.25	+2.7	+1.9	+2.2	+1.6
Max. pig welfare improvement			80.5					

[1] Y denotes Yes, N denotes No

[2] In the base situation, non-lactating sows were tethered. Group-housing or housing in cubicles are mutually exclusive variables; sows could be housed tethered, or in cubicles or in groups.

[3] The amount of roughage fed to hogs was quantified at one-tenth of the daily amount of concentrates.

[4] Additional effects when feeder pigs were supplied by 2 instead of 1 supplier.

Regarding the fattening farm, the highest additional costs were incurred by allowing pigs access to large areas of outdoor space (US$ 4.92 + US$ 2.58 (Table 7.2)). In order for each pen to have an opening to outside space, fattening barns had to be built longitudinally instead of cross-sectionally. As a result, the fattening pig production costs increased by US$ 2.58 (Den Ouden et al., 1996b). Daily supply of roughage and weekly supply of straw to fattening pigs also increased the fattening costs considerably (by US$ 5.69 and US$ 3.56 respectively (Table 7.2)). Here, the extra costs consisted mainly of labour costs. More information on the pig welfare variables and corresponding economics can be found in Den Ouden et al. (1996b).

Since environmental research seems especially focused on measures aimed at reducing N- and P-emissions, considerably less information was available for assessing the environmental effects of the pig welfare variables. The effects of varying floor space and floor type were assessed with the help of experts (Appendix 7.II). In general it was assumed that ammonia volatilization increased if the area of slatted floor space increased. In contrast, increasing the area of concrete floor space at the cost of slatted floor space was assumed to have a reducing effect on N-volatilization in the fattening pen (Verdoes, 1990). Availability of concrete outdoor space was considered as extra ammonia emitting surface, increasing the N-emission as well (Janssen et al., 1989). However, because the pigs spend less time outdoors and the outdoor space was cleaned regularly, the effect was assumed to be only half of that of additional indoor slatted floor space.

In Table 7.2 the conflict between the environmental and animal welfare criteria becomes evident. This holds in particular for outdoor space which is believed to be beneficial to the welfare of the pigs, but at the same time increases N-volatilization by approximately 30% to 64% per pig sold (Table 7.2). Since the increase of the weaning age and number of feeder pig suppliers decrease production efficiency, all environmental criteria are negatively affected as well. The effect of supply of straw and roughage on N- and P-emissions was unclear and was therefore assumed neutral. In contrast to increased volatilization because of more befouling if straw was used (Verdoes, 1990), reduction of volatilization is suggested due to N-binding by bacteria present in straw (Janssen et al., 1989). Less heating and a relatively low GER-value of straw caused the energy consumption per pig to be lower if straw was supplied. Although the effects were relatively small, energy use was increased by all other pig welfare variables (Table 7.2).

7.2.5 Compromise programming model

Costs, pig welfare, and N- and P-emission reduction are the attributes which were jointly included in the compromise programming (CP) model (Romero and Rehman, 1989). The direction of improvement of these attributes - the objectives - are maximization of the pig welfare and the N- and P-emission reduction levels, and minimization of the additional costs incurred. For each of the attributes an acceptable level of achievement, a so-called target, was set. Targets were set equal to the ideal values of each objective. Goals were the combination of each attribute with its corresponding target. For each goal, the extent of underachievement regarding its target was measured by a negative deviational variable, while a positive deviational value measured the opposite, i.e. the overachievement of a goal (Romero et al., 1987; Romero and Rehman, 1989). The pig welfare and emission reduction variables served as decision variables x_i (with x we denote the vector with components $(x_1, x_2, .., x_N)$). Decision variables were either interval-scaled or binary. In general terms, the compromise programming model can be described according to the following equations:

$$\text{Min. } L = \sum_{g \in G} (wn_g * (\frac{1}{Z_g^* - Z_{*g}}) * dn_g + wp_g * (\frac{1}{Z_g^* - Z_{*g}}) * dp_g) \quad (1)$$

Subject to

$$f_g(x) = \sum_{i \in I_g} c_{i,g} * x_i + \alpha_g * \sum_{j \in J_g} xh_{j,g} + (1-\alpha_g) * \sum_{j \in J_g} (c_{j,g} * x_j) + dn_g - dp_g = T_g \quad , g \in G \quad (2)$$

$$xh_{j,g} \leq c_{j,g} * x_j \quad , j \in J, \ g \in G \quad (3)$$

$$xh_{j,g} \leq bigM * Bxh_{j,g} \quad , j \in J, \ g \in G \quad (4)$$

$$\sum_{j \in J_g} Bxh_{j,g} \leq 1 \quad , g \in G \quad (5)$$

$$\sum_{j \in J_g} xh_{j,g} \geq c_{j,g} * x_j \quad , j \in J_g, \ g \in G \quad (6)$$

$$x_i \geq 0, \quad i \in I$$

$$dn_g \geq 0, \ dp_g \geq 0, \quad g \in G$$

$$Bxh_{j,g} \text{ binary}, \quad g \in G$$

$$I = I_g \cup J_g = \{1,2,..,N\}$$

where:

N	=	number of decision variables
G	=	number of goals
L	=	the sum of relatively weighted unwanted deviations of the various goals from their targets T_g
$f_g(x)$	=	the function that describes the contribution of the decision variable x_i ($i \in I$) to the g-th attribute, $g \in G$
dn_g	=	positive deviational variable attached to the g-th attribute, $g \in G$
dp_g	=	negative deviational variable attached to the g-th attribute, $g \in G$
wn_g	=	importance weight attached to dn_g, $wn_g > 0$ if dn_g is unwanted, $g \in G$
wp_g	=	importance weight attached to dp_g, $wp_g > 0$ if dp_g is unwanted, $g \in G$

Z^*_g	=	the ideal value for the g-th objective, $g \in G$
Z_{*g}	=	the anti-ideal value for the g-th objective, $g \in G$
T_g	=	the target value for the g-th objective, $g \in G$
x_i	=	decision variable i, $i \in I$
x	=	vector with components $(x_1,..,x_N)$
$xh_{j,g}$	=	help-variable j, $j \in J_g$, $g \in G$
$Bxh_{j,g}$	=	binary help-variable j, $j \in J_g$, $g \in G$
y_g	=	help variable for the g-th attribute, $g \in G$
$c_{j,g}$	=	contribution of variable j to attribute g, $j \in J_g$; $g \in G$
α_g	=	constant ($0 <= \alpha_g <= 1$) for attribute g, $g \in G$
I	=	index set corresponding to the decision variables
I_g	=	index set corresponding to the linearly related decision variables
J_g	=	index set corresponding to decision variables involved in interactions

In the objective function of the CP-model (equation 1) the sum of all unwanted deviations (dn_g or dp_g) of the various goals from their targets (equation 2) is minimized. As the attributes were measured in different units, i.e. US Dollars, pig welfare points and grams of N- and P-emission reduction, relative rather than absolute deviations were minimized. Moreover, normalization of the deviational variables avoids solutions biased towards objectives that can achieve larger values (Romero and Rehman, 1989). Normalization was established by dividing each absolute deviation by the distance between the ideal value (Z^*_g) and the anti-ideal value (Z_{*g}) of the corresponding attribute g. The anti-ideal value is the worst value of an objective, i.e. the maximum value if the objective is minimized or the minimum value if the objective is maximized (Romero and Rehman, 1989).

The so-called 'help-variables', $xh_{j,g}$ and $Bxh_{j,g}$, and the constant α_g (equations 3 to 6) were used to prevent the total N- and/or P-emission reduction to exceed 100% of the default level and to take account of interactions (Table 7.1). The α_gs were set in such a way that (i) the total maximal N- and P-emission reduction per pig sold equalled about 90% of the N- and P-emission levels of the base situation, and (ii) the emission reductions calculated in the CP-model deviated less than 5% from the simulated emission reduction effects of packages of measures (Table 7.1). Because α_g lies between 0 and 1, the contribution of a certain set of variables to a certain goal is always bigger than the highest individual contribution, but lower than the sum of contributions of all variables included in the set.

7.3 RESULTS

7.3.1 Single criteria optimization

To explore the relation between the various attributes separately, first the attributes 'pig welfare', 'N-' and 'P-emission reduction' were optimized individually by minimizing the cost. This implied a regular linear programming formulation of the optimization model in which the additional costs were minimized under the constraint of meeting increasingly higher targets for the pig welfare, the N- or the P-emission reduction goal (Tables 7.3, 7.4 and 7.5). The targets varied from 10%, 30%, 50% and 70% to 100% of the ideal value. The ideal values of additional pig welfare, N- and P-emission reduction were calculated at 80.5, 1794.5 and 288.6 respectively. The ideal values represent the maximum value of an attribute if all variables with a beneficial contribution to that attribute, i.e. either improving pig welfare or reducing N- or P-emission, were added (Tables 7.1 and 7.2).

Table 7.3 presents the results of the least-cost optimization at increasing targets of pig welfare. To improve pig welfare by 10% of the ideal value, an economic benefit of US$ 2.06 per pig was realized. This was caused by the cost-reducing effects of feeding fattening pigs a ration of three instead of two feeds and restricting the N- and P-levels of the feeds (Table 7.1). As a result, N- and P-emissions were reduced by 252.5 and 52.3 grams per pig respectively. To meet the pig welfare target, the illumination standards were raised to 12 and 20 lux per m^2 in the farrowing and the fattening stage respectively. Simultaneously, the latter caused the energy consumption per pig to increase by 30.1 MJ.

If the pig welfare target was further increased, first the N-emission level reduced further as a result of the increase in concrete floor space. However, because of the increase in outdoor and - slatted - indoor space, N-emission increased thereafter to a maximum of 433.4 grams of N-emission extra per animal sold (Table 7.3). Simultaneously, the additional costs incurred and energy used per animal sold increased progressively as well. The pig welfare variables with the most favourable ratio of improving pigs' welfare at the lowest extra costs were implemented first. More expensive variables, such as increasing the weaning age of piglets and supplying roughage to fattening pigs, were implemented only if the pig welfare target was set at the ideal value (Table 7.3).

Table 7.3 Least-cost (US$/head) solutions for different targets of additional pig welfare levels, varying from 10% to 100%, expressed relative to the ideal value (80.5 = 100%).

	base	stage					
Total costs (US$/head)	187.08		-2.06	+2.24	+8.79	+15.33	+40.63
Pig welfare target	0		+10%	+30%	+50%	+70%	+100%
N-emission level (gr. N/head)	2002.7		-252.5	-259.1	-198.1	+305.7	+433.4
P-emission level (gr. P/head)	302.4		-52.3	-52.3	-52.3	-52.3	-44.1
Total energy level (MJ/head)	3363.2		+30.1	+47.7	+58.9	+77.9	+230.1
Variables		stage					
multiple-stage feeding	N[1]	H[2]	Y	Y	Y	Y	Y
protein restriction feed	N	H	Y	Y	Y	Y	Y
lower P safety margin	N	H	Y	Y	Y	Y	Y
illumination (lux/12 h/day)	N	H	20	20	20	20	20
illumination (lux/12 h/day)	N	F	12	20	20	20	20
concrete space nursery (m^2)	0	F	-	2.31	2.31	2.31	4.0
outdoor space (m^2/sow)	0	F	-	5	5	5	5
tot. space non-lactating (m^2)	1.1/2[3]	F	-	3	3	3	3
concrete space (m^2/place)	0	H	-	0.2	0.29	0.31	0.4
housing non-lactating sows	teth.[3]	F	-	group	group	group	group
straw supplied (kg/hog/week)	0	H	-	-	0.7	0.7	0.7
tot. floor space (m^2/pig place)	0.57	H	-	-	0.72	0.75	0.9
mixing at weaning	Y	F	-	-	N	-	N
outdoor space (m^2/pig)	0	H	-	-	-	1.1	1.1
moving piglets at weaning	Y	F	-	-	-	-	N
straw supplied (kg/sow/week)	0	F	-	-	-	-	1.4
tot. floor space nursery (m^2)	3.75	F	-	-	-	-	6.5
mixing start fattening cycle	Y	H	-	-	-	-	N
automated ventilation	N	H	-	-	-	-	Y
roughage fed (kg/pig/day)	0	H	-	-	-	-	(1/10)[4]
weaning age (weeks)	4	F	-	-	-	-	6

1. N = No (absent), Y = Yes (present)
2. F = Farrowing stage, H = Hog fattening stage
3. Sows could be tethered, housed in cubicles or housed in groups. If housed tethered or in cubicles, total floor space could vary from 1.1 m^2 (default) to 1.4 m^2 per sow. In group housing systems total floor space was assumed to vary from 2 m^2 (default) to 3 m^2 per sow.
4. The amount of roughage fed to fattening pigs equalled one-tenth of the daily amount of concentrates.

In Table 7.4 the results are shown for the least-cost optimization at increasing N-emission reduction targets. Similar to the pig welfare attribute (Table 7.3), an economic benefit (US$ 2.57 per pig) was realized for the 10% target. The same N-emission reduction measures in the fattening stage were the reason for this. Because the environmental measures added to meet the increased 30% target only incurred US$ 1.09 extra costs, a net benefit per pig was also realized for this target level.

Table 7.4 Least-cost (US$/head) solutions for different targets of N-emission reduction levels, varying from 10% to 100%, expressed relative to the ideal value (1794.5 grams of N-emission reduction per animal sold = 100%).

	base						
Total costs (US$/head)	187.08		-2.57	-1.48	+0.15	+4.52	+27.88
N-emission (gr. N/head)	2002.7		-10%	-30%	-50%	-70%	-100%
P-emission level (gr. P/head)	302.4		-53.3	-54.5	-202.1	-278.1	-278.1
Total energy level (MJ/head)	3363.2		-	+3.3	+7.2	+54.4	+399.3
Pig welfare level	0		-	+2.0	+1.7	+2.1	+2.8
Variables		stage					
multiple-stage feeding	N[1]	H[2]	Y	Y	Y	Y	Y
protein restriction feed	N	H	Y	Y	Y	Y	Y
lower P safety margin	N	H	Y	Y	Y	Y	Y
multiple stage feeding	N	F	-	Y	Y	Y	Y
housing adjustments small	N	F	-	Y	Y	-	Y
concrete space (m^2/place)	0	H	-	0.18	0.15	0.20	0.20
covering manure storage	N	H	-	Y	Y	Y	Y
manure processing	N	H	-	-	Y	Y	Y
protein restriction feed	N	F	-	-	-	Y	Y
manure processing	N	F	-	-	-	Y	Y
air cleaning	N	F	-	-	-	Y	Y
concrete space nursery (m^2)	0	F	-	-	-	-	2.3
housing adjustments small	N	H	-	-	-	-	Y
covering manure storage	N	F	-	-	-	-	Y
air cleaning	N	H	-	-	-	-	Y
housing adjustments big	N	H	-	-	-	-	Y
housing adjustments big	N	F	-	-	-	-	Y

1. N = No (absent), Y = Yes (present)
2. F = Farrowing stage, H = Hog fattening stage

Moreover, the increase of concrete floor space in the fattening stage caused the pig welfare level to be improved by 2 points. Similar to the pig welfare attribute, increased N-emission reduction targets caused a progressive increase of production costs and energy consumption. However, in contrast with the pig welfare attribute, increases in the N-emission reduction target did not conflict with the P-emission reduction and the pig welfare goals. P-emission was reduced simultaneously by 278.1 grams per pig (equalling 96% of its ideal value); the pig welfare level slightly improved by 2.8 points (approximately 3% of its ideal value). Again the measures with the most favourable ratio between effectiveness and efficiency, i.e. reducing N-emission at the lowest costs, were implemented first. This involved the feeding measures in particular. More expensive measures, such as big housing adjustments, were implemented only at high N-emission reduction constraints.

Evaluation of the results of the least-cost optimizations at increasing P-emission reduction targets (Table 7.5) indicates cost reductions up to 100% of the target. The extra costs incurred at the ideal value of P-emission reduction are quite low as well.

Table 7.5 Least-cost (US$/head) solutions for different targets of P-emission reduction levels, varying from 10% to 100%, expressed relative to the ideal value (288.6 grams of P emission reduction per animal sold = 100%).

	base						
Total costs (US$/head)	187.08		-2.57	-2.04	-1.32	-0.76	+0.57
P-emission (gr P./head)	302.4		-10%	-30%	-50%	-70%	-100%
N-emission level (gr. N/head)	2002.7		-252.5	-303.1	-358.1	-662.3	-760.3
Total energy level (MJ/head)	3363.2		-	-	+1.8	+4.2	+6.0
Pig welfare level	0		-	-	-	-	-
Variables		stage					
multiple-stage feeding	N[1]	H[2]	Y	Y	Y	Y	Y
protein restriction feed	N	H	Y	Y	Y	Y	Y
lower P safety margin	N	H	Y	-	-	Y	-
multiple stage feeding	N	F	-	Y	-	Y	Y
phytase	N	F	-	Y	-	-	Y
phytase	N	H	-	Y	Y	-	Y
manure processing	N	F	-	-	Y	-	Y
manure processing	N	H	-	-	-	Y	Y

1. N = No (absent), Y = Yes (present)
2. F = Farrowing stage, H = Hog fattening stage

The cost-reducing effects of multiple-stage feeding combined with protein restriction in the fattening stage, and the small number of measures available to reduce P-emission, were the main reasons for this phenomenon. Again the feed measures proved to have a favourable ratio of effectiveness and efficiency. The manure processing option at all stages increased cost, but only marginally. Again there was no conflict with N-emission reduction. At the maximum target of 100% of the ideal value, the emission of N was reduced by 42% of its ideal value (Table 7.5). No impact on the welfare of pigs was assumed. The effect on additional energy use was small (maximal 6.0 MJ per pig sold).

Table 7.6 presents a so-called payoff-matrix. It shows the values of all attributes obtained by optimizing to each single goal individually. The column headings in Table 7.6 present the goals that are optimized. The rows show the values of the attributes obtained in the corresponding single goal optimization. For example, when the additional costs incurred are minimized, the optimization solution equals -US$ 2.57 per animal sold (ideal value (underlined)). Simultaneously, N- and P-emissions are reduced by 252.5 and 52.3 grams respectively. The 'worst' value in a row is often defined as the anti-ideal value (Romero and Rehman, 1989). For each attribute, these values are presented in italics in Table 7.6. This means, for example, that the anti-ideal value of the cost attribute would equal +US$ 40.63 obtained if optimizing the pig welfare improvement goal (Table 7.6).

Table 7.6 Payoff-matrix for the objectives: minimize the additional costs per pig sold (US$/head), and maximize additional pig welfare, N- and P-emission reduction. In each column, the ideal value of an attribute is underlined. Each row shows the 'anti-ideal' value of the corresponding attribute (in italics).

	Costs	Pig welfare	N-emission	P-emission
Costs/pig sold	-2.57	*+40.63*	+27.88	+0.57
Pig welfare	*0*	+80.5	+2.8	*0*
N-emission	-252.5	*+433.4*	-1794.5	-760.3
P-emission	-52.3	*-44.1*	-278.1	-288.6

As can be seen from Tables 7.3 to 7.6, the N- and P-emission reduction objectives do not conflict with each other. This means that they can be optimized simultaneously. Moreover, although all decision variables in this problem do have a cost impact, only a few pig welfare variables influence more than one of the other attributes. As a result, the worst values shown in Table 7.6 were not the worst values possibly attainable. This especially concerned the cost attribute. Because the N- and P-emission decision variables and some of the pig welfare decision variables can be implemented simultaneously, total maximum extra costs will be US$ 72.2 (Tables 7.1 and 7.2) instead of US$ 40.63.

7.3.2 Multi-criteria optimization

In Table 7.7 the multi-criteria programming solutions are presented using the 'payoff' (+US$ 40.63: scenario I) and the real maximum (+US$ 72.2: scenario II) value for the anti-ideal point of the cost attribute. Cost, pig welfare and environmental impact are given equal relative importance. This means that the absolute importance weights of the cost, pig welfare and N- and P-emission objectives are 1, 1, 0.5 and 0.5 respectively (together the absolute importance weights of the emission objectives equal 1). The results in Table 7.7 show that the P-emission objective is always realized. The main reasons for this result are the non-conflicting impact on the other attributes and the relatively low additional costs per animal (Table 7.5). Using the 'payoff' value as anti-ideal for the cost attribute (option I), the relative importance of the cost objective exceeded the one obtained if using the real maximum anti-ideal value (II) because the range between ideal and anti-ideal values was bigger in the latter case (see equation (1)).

Table 7.7 Compromise programming solutions using two different anti-ideal values for the cost attribute, denoted I and II. The relative importance weights of the attributes equal 1:1:0.5:0.5 for 'costs', 'pig welfare', 'N-' and 'P-emission reduction' respectively.

anti-ideal point cost attribute:			I. payoff	II. real maximum
Variables	default	stage		
Total additional costs (US$/head)	187.08		+9.8	+38.5
Pig welfare level	0		+35.3	+70.8
N-emission level (gr./head)	2002.7		-922.6	-1142.4
P-emission level (gr./head)	302.4		-288.6	-288.6
Energy use level (J./head)	3363.2		+59.2	+286.4
Environmental variables[1]				
feed measures	N[2]	H[2]	a+b+d[1]	a+b+d
feed measures	N	F	a+d	a+b+d
farm measures	N	H	h	g+h
farm measures	N	F	e	g+h
manure processing	N	F/H	F+H	F+H
Pig welfare variables				
illumination standards (lux/12 h./day)	N	H	20	20
illumination standards (lux/12 h./day)	N	F	20	20
housing non-lactating sows	teth.[3]	F	group	group
concrete floor space nursery pen (m^2)	0	F	2.3	2.3
total floor space non-lactating sows (m^2)	1.1/2[3]	F	3	3
outdoor space (m^2/sow)	0	F	5	5
concrete floor space (m^2/pig)	0	H	0.2	0.4
supply of straw (kg/pig/week)	0	H	0.7	0.7
mixing unfamiliar pigs at weaning	Y	F	N	N
outdoor space (m^2/pig)	0	H	-	1.1
total floor space (m^2/pig)	0.57	H	-	0.9
moving at weaning	Y	F	-	N
supply of straw (kg/sow/week)	0	F	-	1.4
mixing start fattening cycle	Y	H	-	N

1. *Environmental feed measures*:
   a. multiple-stage feeding
   b. protein restriction feed
   c. lower P margin feed
   d. phytase

   Environmental farm measures:
   e. housing adjustments small
   f. housing adjustments big
   h. air cleaning
   i. covering manure storage
2. F = Farrowing stage, H = Hog fattening stage, Y = Yes, N = No
3. Non-lactating sows were tethered, housed in cubicles (1.1 - 1.4 m^2) or in groups (2 to 3 m^2).

As a result, relative to the other attributes, the cost objective had a higher importance in the first case (I) so the number of - cost incurring - variables included in the optimal solution was lower compared with option (II). Of course, also the extra costs incurred were lower in case of option (I).

Table 7.8 presents the relative importances necessary to realize the ideal value of the various objectives in relation to the other objectives. Again the two options for determining the anti-ideal point of the cost attribute were used for sensitivity analyses.

The importance weights were varied in steps of 1 and 5 points in the ranges of 1 to 100 and >100 respectively.

Table 7.8 Ratio between relative importance weights necessary to optimize each attribute in relation to the other attributes using two different anti-ideal point options for calculating the anti-ideal of the cost attributes as sensitivity analyses. Importance weights were varied in steps of 1 point between 1 and 100 and in steps of 5 points above 100.

Relative importance on:	costs	pig welfare	N-emission	P-emission
anti-ideal point option I: payoff				
weight costs	33	33	33	33
weight pig welfare	1	490	1	1
weight N-emission	1	1	590	1
weight P-emission	1	1	1	15
anti-ideal point option II: real maximum				
weight costs	58	58	58	58
weight pig welfare	1	500	1	1
weight N-emission	1	1	590	1
weight P-emission	1	1	1	15

In Table 7.8 it is shown that the cost objective had to be approximately thirty to almost sixty times more important relative to the other objectives to realize its ideal value (-US$ 2.57/head). Subsequently, the pig welfare attribute had to be nine to fifteen times more important than the cost objective to achieve its ideal value by including all pig welfare decision variables in the optimal solution. Similarly, the N-emission objective had to be eleven to eighteen times more important than the cost objective. The P-emission objective had to be only one quarter to half as important as the cost objective to realize its ideal value.

Figure 7.3 shows the effects of a change in relative importance weighting from environmental preference to pig welfare at the least costs possible. The importance weights used in the calculations as well as the absolute and relative realization of the various objectives are presented in detail in Appendix 7.III. If both the N- and P-emission objectives were at their ideal values, 2.8 pig welfare points (3.5% of its ideal value) were realized. The additional costs incurred in this situation equalled US$ 28.32, which corresponded to an increase of 15% in the production costs in the base situation (US$ 187.08 Appendix 7.I). Similarly, the energy consumption increased by 12% compared with its level in the base situation. When increasing the importance of pig welfare relative to the other objectives, the ideal values of the environmental objectives were maintained until the pig welfare level equalled 45% of its ideal value.

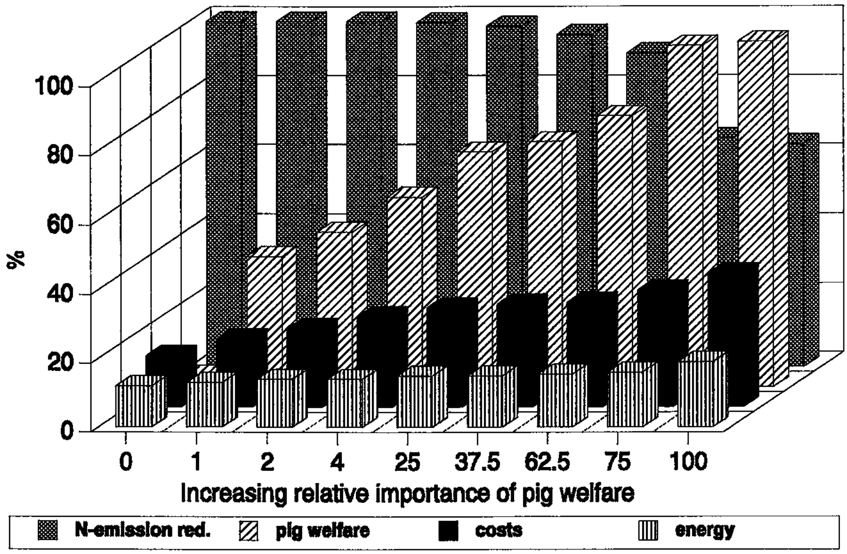

Figure 7.3 Effect of changing the relative importance from environmental preference to pig welfare. N- and P-emission reduction levels, and the pig welfare level are expressed relative to their ideal values. The corresponding additional costs incurred and extra use of energy are expressed relative to the default situation.

A further increase of the relative importance of pig welfare caused the N-emission reduction to decline. The maximal reduction in P-emission could be maintained until 99% of the ideal value of the pig welfare objective was realized. From that point, the increased weaning age of piglets was the only variable which caused the P-emission to increase again. When the ideal value of the pig welfare objective was reached, the optimal solution included all decision variables at their maximum value. The additional costs incurred equalled US$ 72.2, an increase of 39% relative to the production costs in the base situation. N- and P-emission reductions were at 64% and 97% of their ideal values respectively, and energy consumption had increased by 19% relative to the base situation.

As expected, the sequence in which pig welfare decision variables entered the optimal solutions changed compared with the results presented in Table 7.3. In fact, 'access to outdoor space' and 'increases in total floor space' now only entered the optimal solutions if all other pig welfare variables, except the increase in the weaning age, already had been included to improve pigs' welfare (Appendix 7.III).

7.4 DISCUSSION AND CONCLUSIONS

In general, research on measures aimed at reducing environmental pollution and improving animal welfare is relatively slender. Little has been published in scientific journals, if at all. Effectiveness of individual measures and the corresponding economic impacts are often uncertain, let alone their interactions and effects on other attributes (Leneman et al., 1993; Den Ouden et al., 1996a). Maybe because of this, integrated analysis and integrated systems are even further away. To prevent suboptimization of production and distribution systems, integrated research is important. This study was directed at making a contribution in this respect. First individual effects of both environmental and pig welfare measures were estimated along with their corresponding costs. Then interactions among these measures were analyzed.

In general, questionnaire results regarding the relative importance of various pig welfare measures and simulated effects of environmental measures on N- and P-emissions and costs were consistent with the findings of other authors (see Den Ouden et al. 1996a). Compared to Wijnands et al. (1988), N- and P-excretions on sow farms were lower, however. This latter study used older data (1986); in the meantime protein levels of diets have decreased and performance of animals improved. Moreover, the ratio between N-volatilization from the barn and N-excretion we calculated was higher than that found by Leneman et al. (1993). This difference is due to the fact that fattening pigs were housed on fully-slatted floors in this study compared with partially-slatted floors in the case of Leneman et al. (1993). As a result, the N-volatilization per m^2 of total floor space was higher in our case.

The assumption was made that animal welfare measures had no effects on pigs' performance. However, measures aimed at improving pigs' welfare may be expected to relieve the harmful effects of poor production conditions including injuries, mortality or other production losses. On the other hand, some authors have documented negative effects on production performance (Elbers, 1991; Mortensen et al., 1994). Moreover, environmental measures concerning reduction of N and P levels in animal feeds may increase the risk of nutritional deficiencies, consequently inducing the risk of depressed performance (Leneman et al., 1993). The integrated effects of pig welfare and environmental measures on various performance indicators call for future research.

Linear programming and multi-criteria decision making techniques were used in this research to evaluate the relation between economic, pig welfare and environmental aspects of pig farming. Conflicts were found in maximizing pigs' welfare and minimizing environmental pollution. Conflicting variables involved increase in floor space both indoors and outdoors, and increasing the weaning age. Moreover, almost all variables increased the use of energy on the farms. This especially concerned the implementation of a sewer and flushing system (big housing adjustments) and air cleaning systems aimed at reducing N-volatilization from the farm. These measures were also rather expensive. Feeding measures such as multiple-stage feeding and inclusion of phytase proved to be both effective and efficient, i.e. they resulted in low additional costs or even in a net economic benefit per unit of emission reduction. Of the pig welfare measures, raising the illumination standards proved to have a very favourable ratio of 'pig welfare effectiveness' and 'cost efficiency'. Although no effect on N- and P-emissions was assumed, this measure was shown to be rather energy-consuming. Increasing the weaning age of piglets from 4 to 6 weeks proved to be both a very costly measure to improve pigs' welfare and harmful to the environment. By reducing production efficiency, both N- and P-emissions and the use of energy per feeder pig sold increased. As the pig welfare and N-emission reduction objectives were partly in conflict, a simultaneous maximization was impossible. Using the compromise programming model, solutions most close to the ideal point were calculated. Results show that in the case of simultaneous consideration, other pig welfare measures were used to improve pigs' welfare than in the case of a separate evaluation. As expected, measures such as increasing indoor and outdoor space, were implemented only after all other pig welfare measures had already been used. Total additional costs incurred (US$ 72.2 per pig sold) of including all combinational pig welfare and environmental measures accounted for 39% of the original pig production costs from farrow-to-finish.

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Appendix 7.I Some technical and economic input and output in the default situation of the economic pork chain simulation model.

performance INPUT		performance OUTPUT	
Farrowing		***Farrowing***	
max. number of breedings per cycle	3	number of sows present per year	165
litter size (piglets born alive)	10.8	litters/sow/year	2.29
piglet mortality (%)	14.5	feeder pigs sold/sow/year	21.1
weaning age (days)	28	culling rate (%)	40
total floor space nursery pen (m^2)	3.75	number of feeder pigs sold/year	3488
floor space/non-lactating sow (m^2)	1.1	***Fattening***	
Fattening		number of fattening pigs present	2023
daily growth rate (grams)	719	production cycles per year	2.94
number of deliveries/cycle	2	feed conversion	2.80
floor space per pig place (m^2)	0.57	number of fattened pigs sold/year	6200
environmental INPUT		**environmental OUTPUT**	
General		***Farrowing*** (grams/feeder pig)	
N- & P-deposition (kg/ha)	45/1	N-excretion	1550
% of mineral N in manure (%)	50	N-volatilization total	385
manure capacity barn/silo (months)	2/4	% barn/silo/farmland	85/13/2%
GER-value electricity (MJ/kWh)	8.7	N-leaching	152
GER-value gilts (MJ/head)	2161.3	P-excretion	366
Farrowing		P-leaching	87
manure production (liters/sow/day)	14.25	Total energy use (MJ/feeder pig)	756
N- & P-level sow feed (g/kg)	25.60/6.0	***Fattening*** (grams/fattened pig)	
NH_3-volatilization barn (kg N pspy)	8.1	N-excretion	4504
direct energy use pspy (MJ)	4842.2	N-volatilization total	947
Fattening		% barn/silo/farmland	81/16/3%
manure production (liters/pig/day)	3.8	N-leaching	519
N- & P-level finishing feed (g/kg)	26.56/5.0	P-excretion	830
NH_3-volatil. barn (kg N/place/year)	2.68	P-leaching	216
direct energy use/pig/year (MJ)	457.4	Total energy use (MJ/pig)	2608
economic INPUT		**economic OUTPUT**	
General		***Farrowing*** (US$/head)	
labour (US$/hour)	19.7	labour costs	13.3
interest (%)	9.3	housing costs	21.3
straw (US$/1000 kg)	121.2	feed costs	24.1
P_2O_5-surplus discount (US$/kg/ha)	0.15-0.30	manure disposal costs	2.3
Farrowing		other costs	11.7
sow feed (US$/100 kg)	26.8	total costs/feeder pig sold	72.7
feeder pig feed (US$/100 kg)	40.3	***Fattening*** (US$/head)	
manure disposal costs (US$/$m^3$)	10.6	labour costs	7.5
Fattening		housing costs	20.4
start feed (US$/100 kg)	32.5	feed costs	68.8
finishing feed (US$/100 kg)	27.6	manure disposal costs	3.8
roughage (US$/1000 kg)	54.5	other costs	13.9
manure disposal costs (US$/$m^3$)	9.1	total costs/fattened pig sold	114.4

Appendix 7.II Assumed effects of environmental and pig welfare measures on N- and P-levels of feeds supplied and N-volatilization respectively in the farrowing and fattening stage.

Environmental measures	Farrowing			Fattening		
Feeding measures	lactat-ing	non-lactating	piglet	start	growing	finishing
default gr N/kg feed	25.6		29.1	28.0	26.56	
default gr P/kg feed	6.0		6.7	6.0	5.0	
a. multiple-stage feeding (gr N/kg)	25.4	21.6	29.1	28.0	27.2	25.6
multiple-stage feeding (gr P/kg)	6.1	5.7	6.7	6.0	5.0	4.6
b. a + protein restriction (N)	24.0	20.0	27.2	25.6	24.8	23.2
c. a + $\downarrow$ P-safety margin (P)	5.7	5.0	6.3	5.8	4.6	4.2
d. a + phytase (gr P/kg)	5.0	4.6	5.6	4.9	4.4	4.0

Farm measures	Farrowing (default = 100%)	Fattening (default = 100%)
e. housing adjustments small	-15%	-25%
f. housing adjustmenst big	-65%	-50%
g. air cleaning	-80%	-80%
h. covering manure storage	-90%	-90%

Pig welfare measures	Farrowing (NH_3 volatilization)	Fattening (NH_3 volatilization)
- 1% less slatted floor space	-0.85%	-0.85%
- 1% slatted floor replaced by concrete floor space	-0.85%	-0.65%
- 1% more outdoor space	+0.425%	+0.425%
- GER straw & roughage (MJ/kg)	0.2/0.9	0.2/0.9

Appendix 7.III Effects of shifting relative importance from the environmental attributes (N- and P-emissions) to pig welfare while minimizing the additional costs incurred.

	default	ideal value									
Total costs (US$/head)	187.1	-2.6	+28.3	+36.9	+43.6	+50.0	+55.0	+56.2	+57.2	+62.9	+72.2
Pig welfare level	0	+80.5	+2.8	+30.4	+36.6	+44.3	+54.4	+57.5	+63.2	+79.5	+80.5
N-emission level (gr./head)	2002.7	-1794.5	-1794.5	-1794.5	-1794.5	-1789.2	-1771.6	-1726.0	-1630.8	-1188.4	-1154.5
P-emission level (gr./head)	302.4	-288.6	-288.6	-288.6	-288.6	-288.6	-288.6	-288.6	-288.6	-288.6	-280.4
Energy use level (MJ./head)	3363.2	-36.8	+399.3	+441.1	+466.0	+475.4	+509.6	+516.3	+519.4	+535.1	+627.0
Relative (%)	***to:***										
Pig welfare level	ideal	100%	3.5%	38%	45%	55%	68%	71%	78.5%	98.8%	100%
N-emission level	ideal	100%	100%	100%	100%	99.7%	98.7%	96.2%	90.8%	66.2%	64.3%
P-emission level	ideal	100%	100%	100%	100%	100%	100%	100%	100%	100%	97%
Additional costs	default	100%	+15%	+20%	+23%	+27%	+29%	+30%	+31%	+34%	+39%
Energy use level	default	100%	+12%	+13%	+14%	+14%	+15%	+15%	+15%	+16%	+19%
Pig welfare variables	default	stage									
concrete space nursery (m^2)	0	F[1]	2.3	2.3	2.3	4.0	4.0	4.0	4.0	4.0	4.0
concrete floor space (m^2/place)	0	H	0.2	0.2	0.2	0.2	0.37	0.4	0.4	0.4	0.4
illumination standards (lux)	N	H	-	20	20	20	20	20	20	20	20
illumination standards (lux)	N	F	-	20	20	20	20	20	20	20	20
straw supplied (kg/hog/week)	0	H	-	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
housing non-lactating	teth.[2]	F	-	cubi.	cubi.	cubi.	group	group	group	group	group
moving at weaning	Y	F	-	N	N	N	N	N	N	N	N
straw supplied (kg/sow/week)	0	F	-	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
ventilation automated	N	H	-	-	Y	Y	Y	Y	Y	Y	Y
roughage fed (kg/pig/day)	N	H	-	-	(1/10)[3]	(1/10)	(1/10)	(1/10)	(1/10)	(1/10)	(1/10)
total floor non-lactating (m^2)	2	F	-	-	-	1.4	2.45	3.0	3.0	3.0	3.0
mixing at weaning	Y	F	-	-	-	N	N	N	N	N	N
mixing at start fattening cycle	Y	H	-	-	-	N	N	N	N	N	N
total floor space (m^2/place)	0.57	H	-	-	-	-	0.85	0.9	0.9	0.9	0.9
total floor space nursery (m^2)	3.75	F	-	-	-	-	6.5	6.5	6.5	6.5	6.5
outdoor space (m^2/sow)	0	F	-	-	-	-	-	-	5	5	5
outdoor space (m^2/pig)	0	H	-	-	-	-	-	-	-	1.1	1.1
weaning age (weeks)	4	6	-	-	-	-	-	-	-	-	6

1. F = Farrowing stage, H = Hog fattening stage
2. Non-lactating sows could be tethered (teth.), be housed in cubicles (cubi.) or in groups.
3. (1/10) means that the amount of roughage supplied equals (1/10) of the daily amount of concentrated feed.

Chapter 8

GENERAL DISCUSSION

8.1 INTRODUCTION

The research described in this thesis was focused on the development and use of computer models that simulate and optimize economic performance in pork production-marketing chains. The models include three production stages: pig farrowing, pig fattening and pig slaughtering including cutting of carcasses. Transportation of live pigs between these stages was also considered. First, vertical coordination modes in production-marketing chains were described and discussed with special reference to agriculture and product differentiation in pork (Chapter 2). In Chapter 3, an economic pork chain model was developed and described to simulate technical and economic performance of both individual stages and pork chains as a whole. Special attention was focused on the quantification of the way in which stages can influence each other's performance and profitability. The simulation model was used to analyse the distribution of costs and benefits along the stages of the pork chain using various transfer pricing systems (Chapter 4). Besides the chain producing standard pork, three differentiated pork chain concepts were simulated. Chapter 5 described the impact of pig welfare demands on the economics of the pork chain. Pig welfare perceptions were assessed from animal welfare experts, retailers and other consumer-related respondents using a questionnaire based on conjoint analysis of multi-attribute parameters. The estimated pig welfare effects and corresponding economics were used in static and dynamic linear programming models to analyse the development of least-cost chain concepts satisfying increasing demands on pig welfare (Chapter 6). In Chapter 7, the optimization models were extended using multi-criteria decision making techniques to include the effects on nitrogen and phosphorus emissions and energy consumption in pig farming as well.

The vertical chain approach formed the central core of the models presented in the thesis. This approach is an extension of available system simulation models in pork, which primarily focus on analysis of a single farm or agribusiness stage. The models and methods described in this thesis especially focused on cost-benefit analysis, transfer pricing issues, and pig welfare and environmental developments in pork chains. The approach is general in nature and can be used for other product concepts, quality parameters and chain issues as well. In this general discussion the experiences obtained in developing the chain models are reviewed, eliciting both the methods and models used and the implications for the outcomes of the models. Moreover, possible future use in research, industry and governmental policy-making are discussed.

8.2 TYPE OF MODELS AND METHODS

Model span

In the pork chain simulation model, three production stages and distribution in between were considered. Although not all production and distribution stages from conception (nucleus breeding) to consumption (retail) were included, useful insights into the impact of interstage relations and opportunities for studying transfer pricing systems were provided. Addition of stages up- and downstream of the current model may be a useful broadening of the range of results. For example, effects of varying breeds, compound feeds and housing aspects on production performance indicators, such as daily weight gain, had to be assessed from little and diverging literature or experts. As shown in this study (Chapters 3 and 4) the impact of such input values could be very significant, both with respect to single stages and regarding interstage relations. In the same way, assumptions had to be made on market shares. Simulating the effects of hypothetical market demands, their importance was clearly demonstrated (Chapter 4). Useful extension of the pork simulation model will therefore include (i) stages or modules simulating genetic, nutritional and housing effects on pork chain performance and (ii) marketing-distribution stages quantifying expected market demands based on product and consumer characteristics and demand/price-elasticities. With respect to the first, linkage to biological modules of, for example, AUSPIG (Black et al., 1986) seems promising. Priority in adding extra stages to the available pork chain model seems to apply to the marketing side.

Model nature

Simulation models, as developed in this thesis, are a useful tool for studying the potential effects and sensitivities of new developments. Particularly in the case of product differentiation, implying uncertainties regarding both production and market circumstances, this normative approach proved to be useful in exploring the possible consequences of alternative production- and market-situations and in selecting and prioritizing alternative actions before time- and money consuming practical try-outs (positive approach). The big advantage of a - normative - modelling approach is that it allows for sensitivity analyses and adaption of input to new data or renewed insights. As such it forms a flexible and powerful tool both now and in the future, which can usefully support the selection of priorities for future (practical) research.

In the thesis attention was especially focused on - economic - quantification of interstage relations and product differentiation. Some 'logistic ingredients' such as the economic effects of the number of suppliers, the length of production cycles, transportation distances and densities, logistical separation of carcasses of different concept sources and occupation rates of facilities, were also considered in the pork chain simulation model. However, basically it is not a logistic model, supporting decisions on the - optimal - flow of animal and product quantities. Similarly, although some coordination costs were included involving, for example, the cost of audits and extra administration (Chapter 4), focus was not directed at quantification of transaction costs, nor at the economics of organizational and communicational aspects of vertical coordination. However, the various coordination modes themselves may include additional inefficiencies or benefits which, if added to the technical and market performance, turn a chain concept as a whole into an (extra) loss or profit.

Methods

A method widely known in market research, i.e. conjoint analysis (Hair et al., 1990) proved to be very useful in assessing respondents' perceptions of the importance of new market developments such as animal welfare. However, many other aspects are involved in the ultimate perception of pork products. Examples include food safety issues, eating quality aspects, such as flavour and tenderness and the (premium) price of the products. Useful extensions of the questionnaire based on conjoint analysis (Chapter 5) could involve inclusion of such additional criteria, completion by a larger number of respondents and segmentation of respondents. Besides using the results in developing effective communication and marketing strategies, the estimated models could also be expanded to include the effects hereof (Cattin and Wittink, 1982). Moreover, information on size of segments and level of consumer premiums were demonstrated to be of great importance regarding chain profitability and transfer pricing evaluations (Chapter 4).

Conjoint analysis proved to be worthwhile for prioritizing the relative importance of cognizant product attributes. Other methods, however, may be more appropriate for the identification of (new) product attributes relevant to product differentiation. Although the validities of the estimated preference-models and the rate of response to the questionnaire were fairly good (Chapter 5), it took the respondents considerable time to complete the questionnaire. Reduction of the number of profiles per case to a maximum of about 10 and specific allocation of pork stage cases to corresponding experts is advised in further use of conjoint analysis.

Linear programming techniques, including static and dynamic linear programming and multi-criteria decision making approaches, were used to optimize chain concepts according to different criteria. Using input on economic and technical coefficients calculated by the simulation model, the optimization models formed a good complement to the simulation approach. Although various mechanisms are available to linearize non-linear relations and take interactions into account, the increase in computation time when using binary-scaled variables may be the biggest limitation on practical use of this type of models. A worthwhile extension in this respect may include a link to slaughterhouse models such as SNIT-COPT (Sterrenburg et al., 1994) which optimizes carcass supply to meat products demand.

8.3 REVIEW OF MODEL INPUT AND OUTCOME

Availability of information

For quantitative economic evaluation of interstage relations, changing consumer demands, distribution of (extra) costs and benefits, and transfer pricing systems, the models developed need to be fed with technical, economic and marketing data. With respect to the various stages of the pork production-marketing chain, the quantity, confidentiality and, therefore, availability of such information varied considerably. According to Perry (1989) the existence of incentives to conceal private information is related, among other things, to the degree of competition. Indeed, regarding the farm stages with their large numbers of buyers and sellers, both empirical and normative information is widely available. Management information systems, providing daily information on productive performance, are widely used among pig producers in the Netherlands, especially sow farmers (Verstegen et al., 1995). Economic data are also widely available, as is demonstrated by, for example, regular publications of pig farming economics based on technical and economic record keeping information (Anonymous, 1992, 1995). Examples of normative models, and even integration or validation of those in empirical situations, are also numerous (e.g. Black et al., 1986, 1989; Huirne et al., 1992; Jalvingh et al., 1992). Almost the opposite seems to be true concerning economic data on slaughtering. Although some normative models have been described (Lorenz, 1988, 1991; Rasmussen, 1992; Sterrenburg et al., 1994), quantitative results of (practical) applications, seem to be either left to the industrial user or left unpublished or both. Other information available concerns indirect data (Ward, 1990) or quantitative valuations of carcass parameters (Ikerd and Cramer, 1970; Hayenga et al., 1985; Dijkhuizen et al., 1996; Faminow et al., 1996). Economics on livestock transportation also seems to be rarely published, but general transportation data were available.

Time-dependency of input

Besides asymmetric distributions of available data, the information required also concerned issues that were not uniquely defined, such as animal welfare, or issues that had so far been discussed primarily in a qualitative way, for example, agricultural chain-related research. Other information needs involved rather recently-developed issues, such as various pork chain concepts. With respect to the first, conjoint analysis had already been described as a helpful method in assessing pig welfare preferences of individual respondents, based on attributes that were often qualitatively specified or evaluated on different scales. However, 'the positions of animal welfare groups appear to be continually evolving over time' (Lazarus et al., 1991). By their successful campaigns in the field of varying animal welfare topics, consumers may be influenced, showing similar dynamics in concerns. Moreover, new farming systems are being developed. Hence, both the pig welfare attributes and the perceptions assessed and used in this thesis, can expected to be time- and respondent-dependent. Therefore, regular updating is important (Cattin and Wittink, 1982).

The national Dutch research project on integrated quality control in slaughter pigs (Elbers, 1991) was one of the first research projects in - Dutch - pig production that focused on the technical quantification of interstage relations. Economic evaluations were still limited, however. Limitations were also expected regarding recently-developed pork chain concepts and research items, such as environmental evaluations that were still quite young. As described in Chapter 7, little information was available on integrated research on pig welfare and environmental topics. Effects of access to outdoor space, supply of straw and roughage could only be estimated with the help of experts or were assumed to be zero due to the lack of any quantified information at all. Moreover, with respect to environmental impositions, for example, still a major part of the discussions concern fundamental assumptions on biological mechanisms including the role of (animal) nitrogen and phosphorus in acidification and pollution of the environment.

Implications for outcomes

Relating to all these types of incomplete or uncertain data, it has already been mentioned that the simulation modelling approach provides a significant advantage by allowing for sensitivity analyses and adaption of input to new data. Similar arguments may refer to the use of time-dependent data, as for example, the data in this thesis were mainly based on the years 1991 to 1993. In the meantime, production and market circumstances may have changed. Legislation on animal health and welfare, and on animal transportation has restricted (future) pig husbandry and transportation systems to minimum standards including, for example, a minimum floor space of 0.7 m^2, and a ban on fully-slatted floors for fattening pigs, a ban on tethered housing of non-lactating sows, and a reduction of the stock density of hog transportation to 235 kg per m^2. Although usually not present in the default pork chain situations in this thesis, the economic effects of many of these measures were calculated in Chapter 5. Many others might be calculated by modifying input values. The same holds for environmental regulations. For example, since 1992 the amount of animal phosphate applicable to silage corn farmland was reduced from 250 kg to 110 kg in 1995. Moreover, via a so-called 'minerals supply and recording system' Dutch pig farmers had to demonstrate that their 1995 phosphate production was 30% below a predefined level in order to be allowed to maintain their herd size. Since January 1996 small energy consumers have been faced with levies of about Dfl. 0.03 per kWh or m^3 on the use of energy carriers such as electricity and gaz. Using the simulation model, it was calculated that, for example, in the latter case, production costs were increased by approximately Dfl. 0.4 per feeder pig and Dfl. 0.3 per fattened pig sold compared with production costs in the default situation of Chapter 5.

Using the pork chain simulation model, interstage relations were quantified. In the examples presented in Chapter 3, breed types, origin of feeder pigs, and feed types and regimes, seemed to be especially important in this respect. However, in most examples, the interstage effects had a smaller impact on the cost price or income of a particular stage than had the major performance indicators in that particular stage, such as daily weight gain in the fattening stage. Of course, input variables such as daily weight gain or piglets born alive per cycle are, strictly speaking, just technical output of influencing factors such as feed and breed types. In the future, breed effects may be expected to be far bigger than the example presented. This will result from continuous improvements in the quality of estimating breeding values of individual animals. Minimal updating recalculation intervals varying between 6 to 12 months are recommended but will depend especially on the development of new chain concepts or legislation.

Suboptimization and transfer pricing

One of the main goals of this thesis was to analyse whether individual stages, in optimizing their individual goals, could suboptimize the economic chain result as a whole. In Chapter 2, suboptimization was defined as inefficient or inefficacious performance in the production, distribution and marketing of goods in the chain as a whole. This means that the danger of suboptimization will occur whenever activities cause reverse effects between chain and stage economic results. In fact, at the end of Chapter 3 examples were given of alternatives causing the overall chain result to improve while the costs incurred in one or more individual stages increased. One example included the choice of breed type. Whereas the 'Meat' breed type in comparison with the 'White' breed type improved the chain result as a whole, the fattening costs increased. Therefore, at maximizing their individual profits, this may encourage fatteners to choose for the White breed type unless the returns for the Meat breed type pig compensate for the cost disadvantage. However, in analysing the distribution of the net chain profit, it can be calculated that the farrowing stage in particular reaped the benefits, while the fattener still incurred a loss compared with choosing for the White breed type. So, suboptimization may occur indeed. Similar conflicts in distribution of costs or net profit as a result of 'inadequate' transfer prices were found in, for example, the choice of the number of pig deliveries (Chapter 3) and in the analysis of the different chain concepts (Chapter 4). From this it can be concluded that transfer pricing systems can play an important role in potential suboptimization of chain results.

Also the relation between the decision-making unit and the occurrence of the conflict in the chain seems relevant for the chance of suboptimization. For example, under the assumptions described in Chapter 3, integration into one farrow-to-finish operation improved net chain results although the slaughtering result slightly decreased. The latter was by far outweighed by the improvement of the farrow-to-finish result incurred in the 'active' stage(s), i.e. the stage(s) where also the decision (to integrate) is taken. A significant part of the advantage of integrating the farrow and finish operations consisted of technological economies in terms of elimination of the transportation costs of feeder pigs (Chapter 3).

Various so-called 'cost-plus'-based transfer pricing systems were evaluated with respect to their effects on both the level of transfer prices and profits per stage, and the possibility of avoiding conflicts in redistribution of benefits or losses, i.e. to avoid chain suboptimization. All transfer pricing systems, presented in Chapter 4, resulted in a consistent distribution of profits or losses. However, criteria for choosing an 'ideal' transfer pricing system seem to be lacking. The variation between different transfer keys with respect to calculated transfer prices, however, was not that big. Alternative market conditions proved to have a far bigger impact.

Instead of cost-plus-based transfer pricing systems resulting in premiums per animal, transfer keys representing value parameters may be preferred. As shown in the examples of IQC and IQC^+ in Chapter 4, carcasses were found to be of a higher quality. Instead of correcting the cost-plus-based transfer premiums with the carcass quality benefits, these parameters themselves might be a key for redistributing value. As an example the gross margin contribution of a carcass quality parameter was calculated to evaluate potential conflicts with the original carcass quality premiums and discounts. In Figure 8.1 the average gross slaughtering margins per kg of carcass weight are presented for various lean meat percentage classes. Gross margins were calculated both excluding (GMe) and including (GMi) the original premiums and discounts.

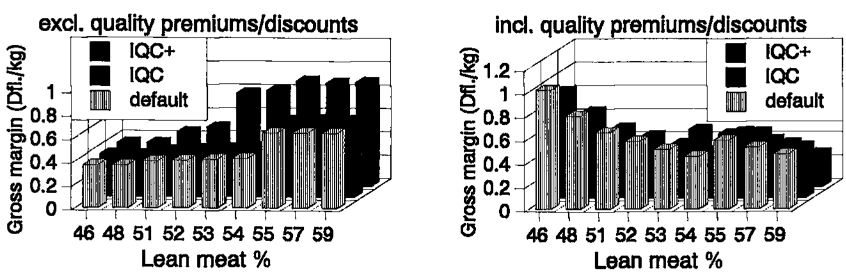

Figure 8.1 Contribution of lean meat percentage to the gross slaughtering margin calculated as the difference between sales and buyers price only (left: excluding the original premiums and discounts) and as the difference between sales price and purchase price including the original premiums and discounts (right).

As can be seen in Figure 1, in general, the higher the lean meat percentage, the higher the GMe. This holds even stronger for the quality concepts IQC and IQC^+. In contrast, almost the opposite trend occurs when the original premiums and discounts are included in the calculation of the gross margin (GMi). The conflicts in redistribution of net chain result found in Chapter 3 were also related to this type of contradictions. Similar discrepancies were found by Dijkhuizen et al. (1996). Based on detailed 1992-1993 data of pork carcass quality parameters and prices, they especially argued to reduce the relatively high premiums and discounts for the parameter 'lean meat percentage'. As the buying price of pork carcasses forms a major part of the total slaughtering costs, and quality premiums serve as important signals to the preceding stages upstream, thorough and continued analysis of transfer premiums will remain an important issue in future research and in practice to reduce the chance of potential chain suboptimization.

8.4 FUTURE OUTLOOK

Besides researchers, future users who can benefit from the developed pork chain approach may be people from industry and government in the first place. Although cost price calculations and evaluations may be of interest to individual farmers, the chain approach makes the model not directly focus on specific items in a single stage. Moreover, as the essence of the model concerns chain issues including product differentiation, vertical linkages and transfer pricing aspects, the model will be suited for strategic or tactical use rather than for operational decision support. With respect to industry, possible applications may range from benchmarking to product development, transfer pricing policies, and negotiations with clients on product characteristics and prices. Particularly, governments have to deal continuously with balancing of - conflicting - interests and development of long-term regulations on issues such as food safety, animal welfare and environmental pollution. For them, the pork chain model may provide useful insights into the economic effects of their actions and support strategic decision making. Examples of applications involve issues such as the timing of introduction of specific measures supporting animal welfare, and the consequences of various priorities on economic, environmental and animal welfare issues.

As shown in Chapter 4, the profitability of - differentiated - chain concepts as a whole and with respect to the individual chain participants will be strongly influenced by market and production risks. Notwithstanding regular evaluations of these risks with potential effects on transfer pricing systems, inclusion of risks in both short- and long-term decision support will be a useful extension of chain research. For example, short-term disease risks can ask for decision support on whether to treat the animals and lose the extra concept value, to withhold medicines and incur production losses or to avoid disease effects by slaughtering the animals at a lower - suboptimal - weight. Moreover, producers can be expected to be interested in maximizing profits but not if it means accepting disproportionately higher risks. The choice for long-term investments in a chain concept will therefore not only depend on the expected average value, but also on the risks involved and the risk-attitude of the decision maker. In the long run, production circumstances, transfer pricing systems and markets or buyer demands may change. Inclusion of risks and risks attitudes may therefore be a useful extension of the current models in future research.

Next to pig production, the chain modelling approach is also suitable for other species. Especially in poultry production where, for example, control of pathogens, such as Salmonella, is an important chain-related topic asking for balancing of efficiency and effectiveness in prevention and control measures to be taken in various stages of the chain (Miles and Butcher, 1993). Certainly risk dimension also plays a role in this respect. As such, the chain approach and models developed for pig production are flexible enough to be transformed to other species and conditions.

8.5 MAIN CONCLUSIONS

- In addition to the large-scale difference between successive farm and non-farm stages, in the literature vertical cooperation is believed to be more appropriate for improving vertical coordination in agricultural production-marketing chains than complete vertical integration. However, in this thesis, complete vertical integration was found to provide benefits, if realized between farrowing and finishing operations.
- The chain modelling approach has shown to be very useful in quantifying and analysing chain systems as a whole. Quantification of interstage relations showed considerable effects of breed type and feed formulation in particular. Reverse economic effects were found in some interstage relations.
- Profitability of differentiated pork chain concepts varied from an additional loss of Dfl. 11.9 per carcass sold in an 'outdoor'-type concept to an extra profit of Dfl. 50.2 per carcass sold in a 'high quality-more welfare'-type concept, compared to standard pork production with average total returns of Dfl. 326 per carcass sold. Net chain profit or loss was redistributed disproportionately among the individual chain participants, however. Inappropriate transfer (premium) prices were found to play a significant part in the potential cause of chain suboptimization.

- Conjoint analysis has shown to be a powerful method in quantifying pig welfare perceptions of individual respondents, based on attributes that were qualitatively specified and evaluated on different scales. The farrowing and fattening stages were considered most important with respect to pig welfare, including issues such as group housing of non-lactating sows, stock densities and illumination standards. In total, pig welfare attributes considered would increase the pig production and distribution costs by 22% to 32%.
- Although the absolute pig welfare perceptions of expert and consumer-related respondents were found to be quite heterogenous, the least-cost chain concepts at lower levels of increasing pig welfare demands were very stable. At higher levels of additional pig welfare demands, extra costs increased progressively and stability of chain concepts declined.
- Conflicts between pig welfare improvement and nitrogen- and phosphorus-emission reduction were found in variables such as increasing indoor and outdoor space per pig and increasing weaning age of piglets. Compared to single criterium optimization, simultaneous optimization of pig welfare improvement, emission reduction and profitability was found to change the sequence in which measures were incorporated in the least-cost pig farming concepts.

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Summary

Introduction

The research described in this thesis was directed towards the development and use of computer models that simulate and optimize economic performance in pork production-marketing chains. The vertical chain approach formed the central core of the research, being an extension of available system simulation models in pork production which primarily focus on analysis of a single farm or agribusiness firm. The models developed involved three production stages: pig farrowing, fattening and slaughtering. Transportation of live pigs between these stages was also considered. The research was especially worked out for cost-benefit analysis, transfer pricing issues and pig welfare and environmental developments in pork chains. The approach, however, is general of nature and can also be used for other product concepts, quality parameters and chain issues.

Literature review on vertical coordination

A literature review was done to obtain background information on vertical coordination systems in agricultural production-marketing chains with special reference to product differentiation in pork (Chapter 2). Since the purpose of the research was especially concerned with the interstage coordination of activities performed in separate organizations, a single stage was 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. The term 'pork production-marketing chain' refers to the combination of vertically related stages or firms through which a pig (product) flows from 'conception to consumption'.

Optimization of individual stages within a Production-Marketing Chain (PMCh) may cause a suboptimal result of the PMCh as a whole. Suboptimization refers to inefficiency and/or inefficacy. That is, the goods in the chain are produced, distributed or marketed neither efficiently nor effectively, in the sense that they fail to match the preferences of the consumers. Market imperfections and conflicting interests may be the causal factors. Although complete vertical integration is often mentioned as the conventional solution, certain disadvantages and the large-scale differences in agricultural PMChs make vertical cooperation a more appropriate alternative. Moreover, specific characteristics of agricultural food chains and changing market circumstances, including increased interest in the quality of products and production processes, justify renewed attention to vertical cooperation and product differentiation in agriculture. In the Dutch pork PMCh, various coordination mechanisms and chain concepts are available in practice including the so-

called Integrated Quality Control (IQC) chain and the outdoor-produced pork chain. Additional requirements include traceability of animals, medicine use with respect to food safety and adaptions of housing and feeding systems aimed at improving pigs' welfare. Although in the literature the importance of a system approach or integral analysis is recognized and potential pros and cons of various coordination mechanisms and chain concepts have been described extensively, there seems to be little quantitative information both at the overall level of the chain and with respect to the individual stages.

Economic pork chain simulation model

An economic chain simulation model was developed for the personal computer to determine the technical and economic consequences of activities performed within the various stages of the pork production-marketing chain (Chapter 3). Effects on both performance per stage and performance of the chain as a whole were simulated taking into account vertical linkages between the stages. Vertical linkages are defined as relationships between the way supplier or buyer activities are performed and the cost or performance of a firm's activities. The chain simulation model included a farrowing, a fattening, and a slaughtering stage, as well as the transportation of pigs between those stages. Integral cost price analysis was the basis of the model, including all costs, those that are independent of and those that depend on the scale of operation per stage. Input values concerned both stage- and chain-related biological and economic variables, and could easily be modified to individual price and production conditions worldwide.

Model output involved the distribution of production costs along the stages of the chain. A sensitivity analysis was carried out to show the effects of various input values and management strategies on both stage and chain results. Quantification of interstage relations showed that many alternatives incurred either increased or decreased costs for all stages of the chain. Some alternatives, however, caused reverse economic effects between the stages considered. For example, integration of the farrowing and fattening stages into one operation instead of into separate specialized units provided benefits for the farm stages while higher - transportation - costs were incurred in the slaughtering stage.

Differentiated pork chain concepts and transfer pricing

The effects of various differentiated pork chain concepts on technical and economic performance of both the chain as a whole and the individual stages were studied using the economic pork chain simulation model (Chapter 4). The differentiation aspects concerned food safety and hygiene, carcass and meat quality, and animal welfare. Compared with standard pork production, two differentiated pork concepts derived additional chain benefits varying from Dfl. 0.7 to Dfl. 50.2 per pig sold, depending on market conditions.

One concept, i.e. outdoor pig production aiming at improving pigs' welfare, incurred an additional loss of Dfl. 11.9 per pig sold. Compared with total returns of Dfl. 326 per carcass sold in the default situation, this is considerable. Benefits and losses were redistributed among the stages of the chain disproportionately. Therefore, a conceptual framework was designed and used to quantify the effects of several transfer pricing systems on the distribution of profit or loss.

Various so-called 'cost-plus'-based transfer pricing systems proved to have a considerable, though smaller, impact on the transfer premiums calculated than did the varying market conditions. However, all transfer pricing systems described resulted in consistently shared extra profits or losses. Generally accepted criteria for choosing a 'fair' transfer pricing system seem to be lacking. However, the effects of the groups of transfer mechanisms described were found to be rather stable. A profound analysis of expected market share and regular updating of transfer prices were found to be of crucial importance.

Inclusion of pig welfare demands in pork chains

In recent years animal welfare has become a major concern to consumers. In developing product differentiation policies to respond to this type of concern, animal welfare preferences have to be related to the cost of production. A questionnaire based on conjoint analysis of multi-attribute parameters was used to quantify pig welfare perceptions of both consumer-related respondents and pig welfare experts (Chapter 5). Economics of the pig welfare concerns was evaluated, using the economic pork chain simulation model.

Results showed that the farm stages farrowing and fattening were considered most important with respect to pig welfare. Important pig welfare attributes included group housing of non-lactating sows, supply of straw, stock density and illumination standards. Respondents were rather heterogenous with respect to their individual quantifications, but no significant difference in response could be found between experts and consumer-related respondents. In total, pig production and distribution costs were increased by 22% to 32% if all pig welfare attributes were included in the pork production-marketing chain.

Optimization model

Static and dynamic linear programming were used to evaluate the development of pork chain concepts that take animal welfare concerns into account (Chapter 6). Pig welfare attributes and the additional costs of production and distribution were balanced. The pig welfare perceptions of both a consumer-related respondent and a pig welfare expert served as input. Pig welfare estimations represented improvements additional to the pig welfare level in the default situation and were expressed on a relative scale from 0 to 100 points.

Results showed that at relatively low levels of additional pig welfare (i.e. ≤ 20 to 30 pig welfare points), especially slaughterhouse- and transportation- related attributes were incorporated into the chain concepts. Examples included the attributes 'reducing stock densities', and 'using automated unloading platforms'. Moreover, 'illumination standards' were raised in both the farrowing and fattening stage. Total additional costs ranged from Dfl. 0.56 to Dfl. 1.20 per pig from the farrowing to the slaughtering stage. Sensitivity analysis showed that the least-cost chain concepts at these low levels of additional pig welfare were very stable. The additional costs incurred increased progressively at higher levels of additional pig welfare to a total maximum (i.e. 100 welfare points), ranging from Dfl. 77 to Dfl. 114.

Economic, pig welfare and environmental issues combined

The economic pork chain simulation model was used to quantify the effects of various measures aimed at either improving pigs' welfare or reducing environmental pollution on economics, on nitrogen and phosphorus emissions, and on energy consumption (Chapter 7). Using linear programming, least-cost pig farming concepts were designed, meeting increasingly higher targets for the level of additional pig welfare or the reduction of nitrogen or phosphorus emission. The environmental and pig welfare measures studied were found to increase farrow-to-finish production costs by 1% to 22%. Both pig welfare and environmental measures increased energy consumption. Similar conflicts were found regarding pig welfare and environmental effects of measures, such as increasing total indoor or outdoor space per pig.

Using multi-criteria decision making techniques, simultaneous optimization of pig welfare improvement, emission reduction and profitability proved to change the sequence in which measures were incorporated in the least-cost pig farming concepts. Shifting importance from environmental to animal welfare targets, a concurrent improvement of both aspects was found until 45% of the pig welfare target was met. After this level, animal welfare improved at the cost of the environmental criteria. At maximum improvement of pig welfare and emission reduction, farrow-to-finish costs per pig increased by 39%.

Main conclusions

- In addition to the large-scale difference between successive farm and non-farm stages, in the literature vertical cooperation is believed to be more appropriate for improving vertical coordination in agricultural production-marketing chains than complete vertical integration. However, in this thesis, complete vertical integration was found to provide benefits, if realized between farrowing and finishing operations.
- The chain modelling approach has shown to be very useful in quantifying and analysing chain systems as a whole. Quantification of interstage relations showed considerable effects of breed type and feed formulation in particular. Reverse economic effects were found in some interstage relations.
- Profitability of differentiated pork chain concepts varied from an additional loss of Dfl. 11.9 per carcass sold in an 'outdoor'-type concept to an extra profit of Dfl. 50.2 per carcass sold in a 'high quality-more welfare'-type concept, compared to standard pork production with average total returns of Dfl. 326 per carcass sold. Net chain profit or loss was redistributed disproportionately among the individual chain participants, however. Inappropriate transfer (premium) prices were found to play a significant part in the potential cause of chain suboptimization.
- Conjoint analysis has shown to be a powerful method in quantifying pig welfare perceptions of individual respondents, based on attributes that were qualitatively specified and evaluated on different scales. The farrowing and fattening stages were considered most important with respect to pig welfare, including issues such as group housing of non-lactating sows, stock densities and illumination standards. In total, pig welfare attributes considered would increase the pig production and distribution costs by 22% to 32%.
- Although the absolute pig welfare perceptions of expert and consumer-related respondents were found to be quite heterogenous, the least-cost chain concepts at lower levels of increasing pig welfare demands were very stable. At higher levels of additional pig welfare demands, extra costs increased progressively and stability of chain concepts declined.
- Conflicts between pig welfare improvement and nitrogen- and phosphorus-emission reduction were found in variables such as increasing indoor and outdoor space per pig and increasing weaning age of piglets. Compared to single criterium optimization, simultaneous optimization of pig welfare improvement, emission reduction and profitability was found to change the sequence in which measures were incorporated in the least-cost pig farming concepts.

Samenvatting

Inleiding

Het in dit proefschrift beschreven onderzoek had als doel om computermodellen te ontwikkelen en toe te passen waarmee het economisch resultaat van varkensketens gesimuleerd en geoptimaliseerd kan worden. De ketenbenadering vormde het centrale uitgangspunt als aanvulling op bestaande simulatiemodellen welke zich primair bezighouden met de analyse van een individueel varkens- of industrieel bedrijf. De ontwikkelde computermodellen omvatten drie schakels, te weten: varkensvermeerdering, vleesvarkenshouderij en varkensslachterij. Transport van levende dieren tussen elk van deze schakels werd ook meegenomen. Het onderzoek is specifiek uitgewerkt voor kosten-baten analyse, evaluatie van verrekenprijzen, dierlijk welzijn en milieu-ontwikkelingen in varkensketens. De benadering is echter algemeen van opzet en kan daardoor eveneens gebruikt worden voor andere produkt-concepten, kwaliteitsparameters en ketenaspecten.

Literatuurstudie naar verticale coördinatie

Om achtergrondinformatie te verkrijgen over verticale coördinatiesystemen in agrarische ketens in relatie met produktdifferentiatie in het bijzonder, werd een literatuurstudie uitgevoerd (Hoofdstuk 2). Omdat het onderzoek met name was gericht op de coördinatie van activiteiten tussen afzonderlijke organisaties, werd een schakel gedefinieerd als de combinatie van activiteiten uitgevoerd tussen twee opeenvolgende markten. De term 'produktie-marketing keten', of kortweg 'keten', heeft dan betrekking op de combinatie van verticaal gerelateerde schakels of bedrijven via welke (varkens-)produkten processen doorlopen van 'conceptie tot consumptie' of van zaadje tot karbonaatje'.

Optimalisatie van individuele schakels binnen een produktie-marketing keten kan leiden tot een suboptimaal resultaat van de keten als geheel. Suboptimalisatie duidt daarbij op inefficiency en/of ineffectiviteit. Dit betekent dat de produkten in de keten noch op een efficiënte noch op een effectieve wijze geproduceerd, gedistribueerd en vermarkt worden. Dit laatste wil zeggen dat ze niet aansluiten bij de wensen van de consument. Imperfecte markten en conflicterende belangen kunnen hiervan de oorzaak zijn. Alhoewel complete verticale integratie onder één eigendom vaak gezien wordt als de conventionele oplossing hiervoor, is als gevolg van bepaalde nadelen van complete integratie en de grote schaalverschillen tussen schakels in agrarische ketens, verticale samenwerking vaak een meer geschikt alternatief. Daarnaast rechtvaardigen de specifieke karakteristieken van agrarische voedselketens en veranderende marktomstandigheden, waaronder de toegenomen belangstelling voor de kwaliteit van zowel produkten als produktieprocessen, de vernieuwde aandacht voor verticale samenwerking en produktdifferentiatie. In de Nederlandse varkensvleesketen komen verschillende samenwerkingsvormen en ketenconcepten voor, waaronder Integrale Keten Beheersing (IKB) en de produktie van scharrelvlees. Additionele eisen van deze ketens betreffen de traceerbaarheid van dieren, het gebruik van medicijnen in verband met voedselveiligheid en aanpassingen van huisvestings- en voedingssystemen met het oog op het verbeteren van het welzijn van de varkens. Hoewel het belang van een holistische of integrale benadering in de literatuur duidelijk onderkend wordt en mogelijke voor- en nadelen van verschillende verticale coördinatiesystemen en ketenconcepten uitgebreid worden beschreven, lijkt er weinig kwantitatieve informatie beschikbaar te zijn zowel op het niveau van de keten als geheel als wat betreft de individuele schakels.

Economisch varkensketen simulatiemodel

Om technisch en economische consequenties van activiteiten uitgevoerd binnen verschillende schakels van de keten door te kunnen rekenen, werd een economisch computer simulatiemodel voor de varkensketen ontwikkeld (Hoofdstuk 3). Zowel effecten op het resultaat per schakel als op dat van de keten als geheel, werden gesimuleerd met inachtneming van verticale relaties tussen schakels. Verticale relaties zijn gedefinieerd als relaties tussen activiteiten uitgevoerd door aanbieders of afnemers en het technisch en economisch resultaat van respectievelijk de vragende dan wel aanbiedende schakel. Het simulatiemodel omvat een vermeerderings-, vleesvarkenshoudende en slachtende schakel als mede het transport van levende dieren tussen deze schakels. Integrale kostprijsanalyse vormde de basis van het model. Inputwaarden betroffen zowel schakel- als keten-gerelateerde biologische en economische variabelen, en kunnen gemakkelijk worden aangepast aan specifieke prijs- en produktieomstandigheden uit andere delen van de wereld.

De output van het model betrof de verdeling van produktiekosten over de schakels van de varkensketen. Bovendien werden gevoeligheidsanalyses uitgevoerd om de effecten van verschillende inputwaarden op de resultaten van individuele schakels en de keten als geheel, te evalueren. Uit kwantificering van verticale relaties bleek dat vele alternatieven een verhoging of verlaging van het economisch resultaat veroorzaakten voor alle in ogenschouw genomen schakels van de keten. Echter, sommige alternatieven leidden tot tegengestelde economische effecten tussen schakels. De integratie van vermeerdering en vleesvarkenshouderij binnen één bedrijf bijvoorbeeld, leidde tot extra baten voor de primaire schakels terwijl in de slachterij hogere (transport-)kosten ontstonden.

Gedifferentieerde varkensketenconcepten en verrekenprijzen

Met behulp van het ontwikkelde economische simulatiemodel voor de varkensketen werden de effecten van drie verschillende gedifferentieerde varkensconcepten gekwantificeerd op het technisch en economisch resultaat van de keten als geheel en de individuele schakels afzonderlijk (Hoofdstuk 4). De differentiatie was gericht op aspecten als voedselveiligheid en hygiëne, karkas- en vleeskwaliteit en diervriendelijkheid. Vergeleken met de uitgangssituatie, leidden twee ketenconcepten tot additionele baten in de keten variërend van f0,70 tot f50,20 per varkenskarkas, afhankelijk van de veronderstelde marktomstandigheden. Eén concept, gericht op het verbeteren van het welzijn van de varkens, leidde tot een extra verlies van f11,90 per karkas. Ten opzichte van een opbrengst van f326,00 per karkas in de uitgangssituatie, zijn dit aanzienlijke effecten. Kosten en baten bleken ongelijk verdeeld te zijn over de verschillende schakels van de keten. Daarom werd een conceptueel kader ontwikkeld en toegepast om de effecten van verschillende verdeelsleutels op de verdeling van winst of verlies, te kwantificeren.

Verschillende zogenaamde 'kosten-plus' verdeelsleutels bleken een aanzienlijk maar kleiner effect te hebben op de berekende verrekenprijzen dan de verschillende marktomstandigheden. Alle beschreven verrekensystemen resulteerden echter in een consistente verdeling van ketenwinst of -verlies. Algemeen geaccepteerde criteria voor de keuze van een 'eerlijke' verdeelsleutel lijken te ontbreken. De gevonden effecten van de verschillende geanalyseerde groepen verdeelsleutels waren echter redelijk constant. Gedegen marktonderzoek en regelmatige updating van verrekenprijzen werden dan ook van cruciaal belang geacht.

Opname van diervriendelijkheidseisen in varkensketens

Diervriendelijkheid is de afgelopen jaren een belangrijk criterium geworden voor consumenten. Bij het ontwikkelen van produktdifferentiatie-strategieën die inspelen op dit type vragen, moeten wensen omtrent diervriendelijkheid afgewogen worden tegen de (extra) produktiekosten. Diervriendelijkheidspercepties van zowel consument-gerelateerde respondenten, zoals detaillisten, en experts op het gebied van het welzijn van varkens, werden gekwantificeerd met behulp van een enquête gebaseerd op conjunct meten (Hoofdstuk 5). De economische effecten van verschillende welzijnsmaatregelen werden geëvalueerd met behulp van het economisch simulatiemodel voor de varkensketen.

Resultaten toonden aan dat de primaire produktieschakels vermeerdering en vleesvarkenshouderij als meest belangrijke schakels werden gezien wat betreft het welzijn van varkens. Belangrijke welzijnsattributen betroffen groepshuisvesting van niet-lacterende zeugen, het verstrekken van strooisel, hokbezetting en verlichtingseisen. Respondenten bleken vrij heterogeen wat betreft hun absolute waarderingen, maar er kon geen significant verschil worden aangetoond tussen de experts en de consument-gerelateerde respondenten. De totale produktie- en distributiekosten namen met 22% tot 32% toe indien alle dierwelzijnsmaatregelen werden opgenomen in de varkensketen.

Optimalisatiemodel

Statische en dynamische lineaire programmingstechnieken werden gebruikt om de ontwikkeling te analyseren van varkensketenconcepten waarin aan diervriendelijkheidseisen wordt voldaan tegen de laagst mogelijke (extra) kosten (Hoofdstuk 6). Dierlijk welzijn en additionele produktiekosten werden tegen elkaar afgewogen. De diervriendelijkheidspercepties van zowel een consument-gerelateerde respondent als een expert dienden als input. De percepties hadden betrekking op verbeteringen van het welzijn van varkens boven het welzijnsniveau in de uitgangssituatie. Ze werden uitgedrukt op een relatieve schaal van 0 tot 100.

Bij minimalisatie van de extra kosten onder voorwaarde van het realiseren van oplopende eisen op het gebied van diervriendelijkheid, bleek dat bij relatief lage additionele diervriendelijkheidseisen (d.w.z. ≤ 20 tot 30 extra welzijnspunten) met name maatregelen in slachterij en gedurende varkenstransport hiervoor in de ketenconcepten werden opgenomen. Voorbeelden van maatregelen waren het verlagen van de bezettingsgraad en het gebruik van automatische laad- en losdeuren. Daarnaast werden in de vermeerdering en de vleesvarkenshouderij de verlichtingseisen verhoogd. Totale additionele kosten in dit traject varieerden van f0,56 tot f1,20 per varken van vermeerdering tot en met slachten. Gevoeligheidsanalyses toonden aan dat de ketenconcepten op deze relatief lage niveaus van additionele welzijnseisen erg stabiel waren. Bij toename van de extra welzijnseisen, stegen de additionele kosten progressief; daarbij totaal oplopend tot een maximum (op 100 extra welzijnspunten) variërend van ongeveer f77,- tot f114,-.

Economische, diervriendelijkheid en milieu-aspecten gecombineerd

Het economisch simulatiemodel voor de varkensketen werd eveneens gebruikt om de effecten te kwantificeren van verschillende diervriendelijkheids- en milieumaatregelen op economisch resultaat, stikstof- en fosforemissie en energieverbruik (Hoofdstuk 7). Met behulp van lineaire programmering werden primaire produktieketens geoptimaliseerd naar minimale (extra) kosten onder voorwaarde van het realiseren van toenemende eisen op het gebied van diervriendelijkheidsverbetering of reductie van stikstof- of fosforemissie. De geanalyseerde milieu- en welzijnsmaatregelen bleken de gecombineerde vermeerderings- en vleesvarkenshouderijkosten te verhogen met 1% tot 22%. Zowel welzijnsmaatregelen als milieumaatregelen vergrootten het energieverbruik. Soortgelijke conflicten werden gevonden tussen dierlijk welzijn en milieu waar het bijvoorbeeld maatregelen betrof die de totale oppervlakte in of buiten de stal vergrootten en daarmee verondersteld werden het welzijn van de varkens te bevorderen maar een negatieve invloed op het milieu te hebben (ammoniakemissie).

Met behulp van doelprogrammering werden diervriendelijkheid, milieu en economisch resultaat gelijktijdig tegen elkaar afgewogen of geoptimaliseerd. Hierbij bleek dat de volgorde waarmee maatregelen werden opgenomen in de geoptimaliseerde ketenconcepten veranderde ten opzichte van de optimalisaties naar één individueel criterium (welzijn **of** milieu). Wanneer het belang werd verschoven van milieu naar diervriendelijkheid, bleek dat een gelijktijdige verbetering van beide doelstellingen haalbaar was totdat 45% van de diervriendelijkheidsdoelstelling was gerealiseerd. Verbetering van het dierlijk welzijn boven dit niveau ging ten koste van het milieu. Bij de maximale toename van diervriendelijkheid met zo hoog mogelijk gelijktijdige stikstof-emissiereductie, bleken de gecombineerde vermeerderings- en vleesvarkenshouderijkosten toe te nemen met 39%.

Belangrijkste conclusies

- Mede door de grote schaalverschillen tussen primaire en agribusiness schakels, wordt in de literatuur verondersteld dat om verticale coördinatie in agrarische produktie-marketing ketens te verbeteren verticale samenwerking meer geschikt is dan complete verticale integratie. In het onderzoek beschreven in dit proefschrift werd gevonden dat verticale integratie winstgevend kan zijn tussen vermeerdering en vleesvarkenshouderij.
- De modelmatige ketenbenadering is zeer bruikbaar gebleken voor het kwantificeren en analyseren van ketens als geheel. Kwantificering van verticale relaties toonde aanzienlijke keteneffecten van met name fokkerij- en voerinvloeden. Tegengestelde economische effecten werden aangetoond in sommige verticale relaties.
- De winstgevendheid van gedifferentieerde varkensketenconcepten varieerde van een extra verlies van f11,90 per varken in een keten gedifferentieerd op diervriendelijkheid, tot een extra winst van f50,20 per karkas verkocht in een ketenconcept gedifferentieerd op karkas/vleeskwaliteit en diervriendelijkheid. Ten opzichte van totale opbrengsten van f326,- per karkas in de uitgangssituatie (bulkproduktie) waren dit aanzienlijke effecten. Ketenwinst of -verlies was ongelijkmatig verdeeld over de verschillende participanten. Onjuiste verrekenprijzen bleken een belangrijke rol te spelen in het mogelijk veroorzaken van ketensuboptimalisatie.

- Conjunct meten bleek een krachtige techniek om diervriendelijkheidspercepties van individuele respondenten te kwantificeren gebaseerd op veelal kwalitatief gespecificeerde kenmerken die bovendien in verschillende eenheden werden uitgedrukt. De vermeerdering en de vleesvarkenshouderij werden als meest belangrijke schakels beschouwd ten aanzien van het welzijn van varkens. Voorbeelden van belangrijke maatregelen waren groepshuisvesting van niet-lacterende zeugen, hokbezetting en verlichting. In totaal bleken de in ogenschouw genomen diervriendelijkheidsmaatregelen de varkensproduktie- en distributiekosten te kunnen verhogen met 22% tot 32%.
- Hoewel absolute individuele diervriendelijkheidspreferenties van experts en consument-gerelateerde respondenten tamelijk heterogeen bleken, waren de naar minimale extra kosten geoptimaliseerde ketenconcepten zeer stabiel bij relatief lage extra diervriendelijkheidseisen. Bij toename van de diervriendelijkheidseisen stegen de extra kosten progressief en nam de stabiliteit van de ketenconcepten af.
- Conflicten tussen diervriendelijkheid en milieu in de vorm van reductie van stikstof- en fosforemissie, werden gevonden in maatregelen zoals het vergroten van het oppervlak per dier en het verlengen van de speenleeftijd van biggen. Ten opzichte van optimalisatie naar een individueel criterium bleek bij gelijktijdige optimalisatie van diervriendelijkheid, milieu en economisch rendement dat de volgorde veranderde waarin maatregelen werden opgenomen in de varkensketenconcepten.

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Curriculum vitae

Marjan den Ouden werd op 31 augustus 1967 geboren in Alblasserdam (Zuid Holland). In 1985 behaalde zij aan het Murmellius Gymnasium te Alkmaar het Gymnasium-B diploma. In september 1985 begon zij met de studie Zoötechniek aan de toenmalige Landbouwhogeschool Wageningen. In augustus 1990 rondde zij de studie Zoötechniek met lof af met als afstudeervakken Veehouderij en Agrarische Bedrijfseconomie. Haar stage voerde zij uit bij Hendrix Voeders B.V. te Boxmeer. Na haar afstuderen was zij tot september 1993 werkzaam als toegevoegd onderzoeker bij de vakgroep Agrarische Bedrijfseconomie van de Landbouwuniversiteit Wageningen hetgeen heeft geleid tot dit proefschrift. Het onderzoek voor dit proefschrift werd uitgevoerd in nauwe samenwerking met Nutreco Nederland B.V. Van september 1993 tot juli 1996 was zij in dienst van Hendrix Voeders B.V. te Boxmeer. Naast het voltooien van haar proefschrift, werkte zij hier onder andere aan Salmonella-projecten in de vleeskuikensector en aan een economische strategie-studie voor Nutreco. Sinds juli 1996 is zij werkzaam bij Nutreco Nederland B.V. als poultry researcher voor het Nutreco Poultry Research Centre in Spanje.