Fødevareøkonomisk Institut

Rapport nr. 168

Provision of quality attributes in the food marketing chain: an optimization approach

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Copenhagen 2004

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Preface

The Danish food industry faces pressures to increase value-added and to improve efficiency. At the same time, policy increasingly targets industry conduct and the attributes of food products such as their safety, and ethical issues of their raw material production. Recognizing that food quality attributes are delivered by co-ordinated action amongst food industry firms, the research presented here examines relationships and incentives within the food marketing chain.

This research is part of the 3-year project "Perspectives for Development of the Danish Food Sector". The project targets the policy environment surrounding the Danish food marketing chain, and has objectives to:

1. measure changes in function, structure and commercial practice in the Danish food industry, and compare and contrast these with developments in other countries;
2. characterize vertical and horizontal relationships in the Danish food chain, and their role in efficiency;
3. evaluate the efficiency and competitiveness of the Danish food system at each stage of the marketing chain;
4. review and evaluate instruments of Danish, EU and foreign public policy in the development of the food marketing chain; and
5. communicate research results in a number of media.

The research reported here is associated with objectives 2, 3 and 4. Efficiency in the provision of food quality attributes by the Danish food marketing chain is examined. A mathematical program is used to model incentives for provision, which include firms' free-riding behaviour within the food chain. Scenarios presented include a range of technological conditions; the allocation of retail price premia amongst stages; and the implications of mandatory provision of an unprofitable attribute. Results list provision outcomes, profitability and its distribution amongst chain participants, and the implications of non-provision by firms.

Commercial applications of the research include its focus on within-chain compensation. Notably, the model generates measures of profits and loss that can be applied in designing new compensation regimes. Desirable extensions to the research include it use of more detailed and accurate input data, and comparison of its output to commercial profitability and compensation patterns. Policy applications include its treat-

ment of options for design of mandatory provision, and interactions between market power and the allocation of benefits within the food marketing chain.

The project is partially funded by the Innovations Law of the Danish Ministry of Food and Agriculture. Early versions of the models and early drafts of the report were reviewed by Jørgen Dejgaard Jensen.

Danish Research Institute of Food Economics, September 2004.

Søren E. Frandsen

1. Introduction

1.1. Background and motivation

Food products are marketed as a composite of attributes. Attributes desired by consumers extend beyond nutrition to include food safety, environmental concerns, convenience and ethics (Caswell, 1998; Henson and Traill, 2000). The complete list of a product's (infinite number of) attributes fully defines its quality. Empirical work uses a shorter list, such as Hooker and Caswell's (1996), that subdivided quality into five categories (see table 1.1).

Table 1.1. Examples of food quality attributes

Categories of food quality attributes				
Food Safety	Nutritional	Value	Packaging	Process
• Food-borne pathogens • Heavy metals • Pesticide residues • Food additives • Naturally-occurring toxins • Veterinary residues	• Fat • Calories • Fibre • Sodium • Vitamins • Minerals	• Purity • Compositional integrity • Size • Appearance • Taste • Convenience of preparation	• Package materials • Labelling • Other information	• Animal welfare • Biotechnology • Environmental impact • Pesticide use • Worker safety

Source: Hooker and Caswell (1996)

The Danish food marketing chain offers consumers a range of sophisticated food attributes in what is reckoned to be a high-cost environment (National Committee on Pig Production, 2004; Danish Poultry Council, 2004). In Denmark's increasingly concentrated food industry (Baker, 2003), co-ordinated action amongst food chain participants is becoming more commonplace and more demanding (Esbjerg, 1999). Such co-ordination involves the development and use of mechanisms for allocating and sharing costs and rewards arising from attribute provision (Strandskov et al., 1999).

Commercial initiatives within the food marketing chain include Efficient Consumer Response management systems (ECR - King and Pomphiu, 1996) and the EUREP-GAP initiative in the European fruits and vegetables chain (Brouwer and Bijman, 2001). Addressing longer term development in products and processes, Boon (2001)

examines the means by which linkages between stages of the food marketing chain facilitate innovation in four Danish food-farm sectors.

Under-provision of food quality attributes is frequently used as a justification for policy intervention. Across a range of food sectors, Danish firms interpret policy interventions as cost increasing, but those costs may be able to be passed on down the food chain as price increases (Baker et al., 2004). In the case of food safety, Danish action has featured chain co-ordination and public-private partnership in some cases. Wegener et al. (2003) describe these elements of control programmes for *Salmonella* in pork, chicken and shell eggs, which focused on "pre-harvest controls" (i.e. action at farm level) rather than (downstream) bacteriological testing "because of the higher cost involved and logistical problems". Dansk Industri's (2002) survey of food industry firms found that the broader topic of "food quality" was addressed in a less co-ordinated way: responding firms tended to allocate the responsibility for quality to other members of the food marketing chain, in the manner of free-riders.

Identifying and reacting to under-provision is thus a problem confronting food industry firms, co-ordinated food marketing chains, and government. The current paper addresses the efficiency with which consumer demand for food product attributes might be satisfied by the Danish food marketing chain. In particular, provision is possible at more than one stage of the chain, and can occur in portfolios of products with a particular attribute and as products with multiple attributes. Moreover, provision occurs under a range of competitive conditions that alter and offset technological considerations. The current paper examines these factors using indicative data, and identifies implications of policy responses to perceived under-provision.

1.2. Attribute provision in the food marketing chain

Representation of the food marketing chain

The food marketing chain is often viewed as "a vertical slice of the economy" (Wright, 1996), wherein a vertical array of agents pass products between stages. Traditional analysis has envisaged markets operating between stages, and flows of product and information moving along the chain. Recent interpretations include dynamic shifts of product and input flow (Boehlje and Sonka, 1998; Collins, 2001), complex cyclical information flows (Kinsey and Senauer, 1996), and the conversion of discrete

stages into "channels", featuring cost and demand interactions (Price, 2002; Hughes, 2002).

Measurement of attribute provision

Antle (2001) presents a theoretical model of quality provision, where quality is assumed to be a measurable continuous variable. However, most empirical studies of attribute-specific costs and revenues are based on all-or-nothing scenarios (i.e. provision or non-provision). Examples include studies of costs of control of individual contaminants or pathogens in the meat industry by Jensen et al. (1998) and Narrod et al. (1999). Examination of how such costs change over a range of levels of effectiveness (Antle, 2000) has been used to introduce quasi-continuity of attribute variables.

Studies of the cost impacts of environmental policies on the food industry have also used all-or-nothing attributes, as in Gren's (1994) study of farm-level responses to policies on pesticide use. Maltsberger and Kalaitzandonakes (2000) compare grain handling costs "with" and "without" the traceability attribute, and Offermann and Nieberg (2002) take the same approach to study the costs of provision of organic farm produce.

On the revenue side, Hobbs (2003) estimates retail price premia for selected attributes (information about the food safety and traceability status of sandwich fillings) in an all-or-nothing format. Hobbs also treats combinations of attributes as separate attribute specifications. Govindasamy et al. (2001) use a logistic regression approach to estimate willingness to pay for the all-or-nothing variable "integrated pest management produce". Galletto (2003) reports livestock price premia at slaughter to compare organic/non-organic animals in one market in Italy. Caswell's (1998) national-level policy analysis treats food safety as a "with" and "without" attribute.

Information and attributes

Consumers' purchasing decisions are motivated by information about the product, rather than the product itself. That information becomes known to the consumer either at purchase or after purchase, or perhaps not at all (Nelson, 1970). The information shortfall is overcome by "signals", the best known of which are brands and certificates. Some signals are provided by government (e.g. Danish Ø-marque organic certification), others mandated by government (e.g. identity preservation in the meat marketing chain) and others are voluntarily provided by firms (e.g. statements on egg

containers about the housing conditions of the producing hens). Wegener et al. (2003) describe voluntary Salmonella classification systems for pigs in Denmark, and the generalised strength of the Danish food safety system that allowed beef sales to be largely unaffected during health scares elsewhere in Europe.

The current paper interprets signalling as part of attribute provision, but it is recognised that this is a significant simplification. In particular, signals are often generated by agents other than those that provide attributes, and by coalitions of agents (e.g. a co-operative or a firm that owns many plants). The inclusion of signalling costs is a logical extension of the model developed in this paper, but is not considered further here.

1.3. Attribute provision incentives

Revenues

Consumers' willingness to pay for a product attribute is expressed as a price premium at the retail stage of the food chain. A share of this premium is passed to the next agent on the food chain, from whom the retailer buys the product (distributors, wholesalers, processors). Shares of that share are passed to members of the food chain further upstream, and onwards to farmers and suppliers of farm services and inputs. At each stage of the chain, firms' attribute-related revenues reflect both the size of the premium and the share received. All firms in the food marketing chain receive non-negative attribute-related revenue, regardless of which member of the chain provides the attribute.

Technology

Provision incurs costs. Although firms at non-providing stages of the food chain do not incur provision costs, they may face some costs associated with preserving the attribute through to sale (e.g. separate storage) or presenting it for sale (e.g. separate space in a display freezer). Non-provision costs are not considered further here, but are a simple extension of the model presented below.

Provision technologies are likely to feature economies of scale. This might result from allocation of fixed costs (e.g. per unit costs of certification programmes will be lower, the higher the volumes handled) or convex technologies (e.g. reduced chilling

costs from full utilisation of chilling space, or efficiencies from larger pipe diameters in flow processes).

Provision technologies are also likely to feature economies of scope. These might have two manifestations: cost savings from providing the same attribute across different products (e.g. applying an existing vegetable organic certification system to a fruit product line); and cost savings from providing more than one attribute to the same product (e.g. organic chicken would normally qualify as free range chicken). Notably, these scope economies can work in reverse (e.g. provision of free range livestock will add significant costs to any attempt at provision of product that is free of contamination by a specific bacterium).

The current paper sketches those relationships and costs, and derives alternative attribute provision outcomes. The impacts of each outcome on profitability and efficiency are examined. The potential for between-stage compensation is examined by using two contrasting objective functions (whole-chain optimisation and single-stage optimisation) and by examining dual values.

Uncertainty

Although both the size of the premium and the share received are subject to uncertainty, the following assumes that they are both known in magnitude and certain in occurrence. Similarly, cost characteristics are also assumed known. Relaxing such assumptions represents a potential extension of the model developed here, although maintaining them does not detract from the analysis as presented.

1.4. Issues of efficiency

Least-cost provision

An intuitively efficient result is that provision occurs at the stage of the food chain featuring the lowest provision cost. However, whether or not that occurs also depends on profitability, namely the size of available price premia and the share allocated to the firms at each stage. Where costs feature economies of scale and scope, the portfolio of products and attributes for a firm at each stage will also influence the provision decision.

Externality

For a firm, attribute provision requires a positive profit outcome at that firm's stage of the food marketing chain. For the chain as a whole, attribute provision is desirable if benefits to the entire chain exceed costs to the whole chain. Because costs of provision may accrue to just one stage and benefits accrues to all, then the potential exists for a market failure: all stages have the incentive to let other stages provide the attribute.

Compensation

Single-stage optimisation that features under-provision may be (theoretically) overcome by compensation of one stage of the food marketing chain by another. In this way an optimal whole-chain solution might be implemented.

Policy response

Policy response to market failure in the food marketing chain is linked to the nature of private incentives. Where non-provision[1] is interpreted as being socially or ethically undesirable, mandatory provision (e.g. salmonella control) is one possible response. The mandating authority must choose, perhaps arbitrarily, which stage of the food chain will undertake provision. Having made the choice, a further option is to tax one or more stages of the food marketing chain to recover administration costs and/or to compensate the provider for added costs.

These choices may not yield a least-cost outcome and are likely to generate profits for non-providing stages. Other policy responses include state provision (e.g. food safety certification) or subsidisation (e.g. for farmers' conversion to organic milk production), or state-funded promotions to increase consumer willingness to pay (e.g. generic dairy promotion). In all cases, the efficiency implications of a policy intervention can be examined by improved knowledge of the incentives for attribute provision and the ways in which costs or competitive structures affect them.

[1] The symmetric argument (where the attribute is considered socially undesirable) is not considered here.

1.5. The report

Purpose

This report summarises work on developing a model of the food marketing chain that examines the economics of food product attribute provision. From a set of estimates of attributes' price premia and provision costs, the impact of pricing, technologies, and policy interventions is examined. Alternative approaches are taken to the issue of optimal provision: "whole chain" vs. "single stage".

The report identifies situations in which attribute provision appears, disappears, and switches from one stage to another in the food marketing chain. In addition to provision, profitability is recorded and compared amongst scenarios. This allows measurement of externalities and prescription of within-chain compensation. It also allows examination of aspects of government-mandated provision.

Audience

This report has three audiences. Food industry firms are invited to examine the model for applications to their own attribute provision decisions, their positioning within the food chain, and the impacts of food industry policies they encounter. The second audience is the Danish food policy establishment: this work offers a systematic examination of food attribute provision under a range of cost, revenue and policy scenarios. The third audience is the agricultural economics profession, for whom this report is a contribution to understanding of food attribute provision and relationships in the modern food chain.

Structure

This report has five sections. Section 2 details the mathematical programming model used to examine firms' attribute provision decisions. Section 3 describes and explains the scenarios examined, and section 4 lists the results. Section 5 is a discussion of the procedure and the results, and the practical extensions and applications of the work.

2. Analytical model

2.1. Approach taken

In this research, food attribute provision is interpreted as a static optimisation problem in the absence of uncertainty over costs and revenues. The incentives discussed above are represented by a profit function that includes complexities of revenues and costs that reflect competitive and technological features of the food marketing chain. Competitive features target the shares available to each stage of the chain of the retail price premium that the consumer pays for the attribute. Technological features address economies of scale and scope that are likely to influence costs of provision across a range of scenarios.

Provision of attributes is presented as an all-or-nothing event. This means that attributes are either endogenously provided in the model, or not, with no intermediate or partial provision. Free-rider incentives are addressed by the model's allocation of costs to just one stage of the chain (the provider) while benefits are shared throughout the chain. For this reason, two objective functions are needed: a "whole chain" optimisation that maximises profits to the whole chain; and a "single stage" optimisation that maximises the profits of any stage that provides the attribute. While the whole chain internalises free-riding, the single stage model leaves it as an externality that may result in under-provision.

The model does not include a component that maximises consumer welfare: consumers' willingness to pay for attributes is included exogenously. Social objectives are also not included in the objective function, but some scenarios examine the prospect of provision of attributes for which costs exceed financial returns in the food marketing chain.

Scenarios are constructed to examine the sensitivity of the model to alternative cost and revenue specifications, and to identify key impacts of provision that might be mandated by policymakers. Associated with each solution are the list of attributes provided, and the stage at which provision occurs. Profits at all stages of the chain are also reported, along with sensitivity analyses that chart the implications of non-provision. Comparisons of the whole chain and single stage models allow commentary of the prospects for within-chain compensation (i.e. one agent to another) and subsidisation (from outside the chain) to invoke attribute provision.

2.2. Conceptual model

Stages, products and attributes

A stage $s \in S$ of the food marketing chain delivers volume y_{ik}^{s}, where $i \in I$ are products with $k \in K$ quality attributes.

Quantities and price premia

The consumer receives volume y_{ik}^{R}, where $R \in S$ is the retail stage. Price premia p_{ik}^{s} apply $\forall$ i,k and s. Price premia are allocated amongst stages s according to $p_{ik}^{s} = \Psi_{ik}^{s}.p_{ik}^{R}$ $\forall$ s, where Ψ_{ik}^{s} is an allocation received at stage s, and $\sum_{s} \Psi_{ik}^{s} = 1$. Ψ_{ik}^{s} is treated below as exogenously determined, but may be the outcome of bargaining, or of other institutional processes not examined further here.

Costs of provision

At each stage agents face costs of attribute provision $c_{ik}^{s}(\mathbf{w}, y_{ik}^{s}, y_{jk}^{s}, y_{il}^{s})$, where $\mathbf{w}$ is input prices[2] and arguments y_{jk}^{s} and y_{il}^{s} imply opportunities for economies of scope due to cost sub-additivity between products $i,j \in I$ ("i-form") and/or attributes $k,l \in K$ ("k-form").

Profits

Across all products and attributes, profit for the whole chain is

$$\Pi = \sum_{s} \sum_{i} \sum_{k} \left[\Psi_{ik}^{s}.p_{ik}^{R}.y_{ik}^{s} - c_{ik}^{s}(\mathbf{w}, y_{ik}^{s}, y_{jk}^{s}, y_{il}^{s}) \right]. \tag{1}$$

Note that agents benefit from receiving $p_{ik}^{s} = \Psi_{ik}^{s}.p_{ik}^{R}$ at every stage s, but $c_{ik}^{s}(.)$ is paid by only one stage.

[2] Appearance of the argument **w** does not preclude imperfect competition in input markets, implying **w**(**x**) for input **x**. However, it is not considered further here.

2.3. Specification of empirical model

Attribute provision as a variable

Agents' choices regarding attribute provision at each stage of the food marketing chain employs (1) as a mathematical programming problem with choice variable A_{ik}^{s} such that

$$A_{ik}^{s} \equiv \begin{cases} 1 \text{ if quality attribute is present} \\ 0 \text{ otherwise} \end{cases} \quad \forall\ i,\ k \text{ and } s.$$

To mobilise a non-linear programming model[3] with meaningful dual interpretation, A_{ik}^{s} is not strictly a binomial variable, but rather is specified in the constraint set as

$$0 < A_{ik}^{s} \leq 1\,. \tag{2}$$

Maximization ensures that A_{ik}^{s} =1 in the case of provision, with multiple-stage provision precluded by the constraint

$$\sum_{s} A_{ik}^{s} \leq 1\,. \tag{3}$$

Objective function for whole-chain optimisation

Combining (1), (2) and (3) provides the objective function to maximise whole chain profits (WC):

$$\max_{A_{ik}^{s}} WC = \sum_{i}\sum_{k}\left[\begin{array}{l} \Psi_{ik}^{s} p_{ik}^{R} \sum_{s} A_{ik}^{s} y_{ik}^{s} \\ -\sum_{s}\left[FC_{ik}^{s} A_{ik}^{s}.\left(1-\sum_{l\neq k}\Upsilon_{il}^{s} A_{ik}^{s} A_{il}^{s} - \sum_{j\neq i}\Upsilon_{jk}^{s} A_{ik}^{s} A_{jk}^{s}\right)\right] \\ -\sum_{s}\left[\left[AVC_{ik}^{s} A_{ik}^{s}.\left(1-\sum_{l\neq k}\Lambda_{il}^{s} A_{ik}^{s} A_{il}^{s} - \sum_{j\neq i}\Lambda_{jk}^{s} A_{ik}^{s} A_{jk}^{s}\right)\right].(y_{ik}^{s})^{\rho_{i.k}^{s}}\right] \\ +\sum_{s}\lambda_{ik}^{s}\left(1-A_{ik}^{s}\right) \end{array}\right] \tag{4}$$

[3] The model was specified in GAMS 2.50C (GAMS Development Corporation), and run in the Windows NT environment accessing Microsoft Excel spreadsheets. The Data exchange between GAMS and Microsoft Excel used the downloadable macro XLS2GMS version 1.6 (Kalvelagen, 2002).

The first RHS expression in (4) is whole-chain revenue, the second is fixed costs of attribute provision, and the third is variable costs of attribute provision. Economies of scope are available from provision of multiple k (k and l, $k \neq l$) and from multiple i (i and j, $i \neq j$). Cost sub-additivities in fixed costs are denoted Υ and in variable costs Λ, expressed as a % saving in costs resulting from multiple attributes and/or multiple products. Economies of scale are modelled by parameter $0 < \rho_{ik}^{s} \leq 1$.

Note that in (4) whole-chain revenue is activated by the attribute provision A_{ik}^{s} at any stage (via $\sum_{s} A_{ik}^{s} = 1$), but costs of attribute provision accrue only to the stage at which provision occurs (via $A_{ik}^{s} = 1$). This means that so long as overall net benefits to the food marketing chain are positive, then the attribute will be provided in the solution. A possible outcome is that provision will be unprofitable for the providing stage, but profitable for the chain as a whole. Losses to the provider (and to other non-providing stages) are measurable, and represent a lower bound for potential compensation from stages that benefit from provision.

Dual variables for whole-chain scenarios

At the optimum, LaGrangian multipliers λ_{ik}^{s} provide valuations of attributes for which $A_{ik}^{s} = 0$. In that context, $\lambda_{ik}^{s} < 0$ implies a "provision threshold" for levels of profitability at each stage, so that $|\lambda_{ik}^{s}|$ = the loss to the entire food marketing chain from provision at stage s of A_{ik}^{s} $\forall$ i and k. Alternatively, $|\lambda_{ik}^{s}|$ = the subsidy necessary to induce provision at stage s. In each solution, as conditions approach those favourable for attribute provision at any s, $\lambda_{ik}^{s} \rightarrow 0$ from below.

Objective function for single-stage optimisation

A different revenue specification yields an alternative objective function in (5). Provision ($A_{ik}^{s} = 1$) focuses on revenue accruing only to the stage at which the attribute is provided. This objective function allocates attribute provision to the most profitable stage, but unlike (4) only the profits at the provision stage (ST) are maximised. In this case, revenue accruing to non-providing stages is a positive externality. Whole chain revenue and profit is still able to be measured from post-solution optimisation.

$$\max_{A_{ik}^s} ST = \sum_s \sum_i \sum_k \begin{bmatrix} \Psi_{ik}^s p_{ik}^R A_{ik}^s y_{ik}^s \\ -FC_{ik}^s A_{ik}^s . \left(1 - \sum_{l \neq k} \Upsilon_{il}^s A_{ik}^s A_{il}^s - \sum_{j \neq i} \Upsilon_{jk}^s A_{ik}^s A_{jk}^s \right) \\ -AVC_{ik}^s A_{ik}^s . \left(1 - \sum_{l \neq k} \Lambda_{il}^s A_{ik}^s A_{il}^s - \sum_{j \neq i} \Lambda_{jk}^s A_{ik}^s A_{jk}^s \right) . (y_{ik}^s)^{\rho_{i.k}^s} \\ +\upsilon_{ik}^s \left(1 - A_{ik}^s \right) \end{bmatrix} \quad (5)$$

Dual variables for single-stage scenarios

LaGrangian multipliers from $\upsilon_{ik}^s < 0 \; \forall \; A_{ik}^s = 0$ are interpreted as the loss to the individual stage from provision. In general, $\upsilon_{ik}^s \neq \lambda_{ik}^s$, because υ_{ik}^s measures the potential impact of stage *s*'s provision on stage *s* profits, whereas λ_{ik}^s in (4) measures the potential impact of stage *s*'s provision on whole chain profits. The relationship between the two LaGrangian multipliers offers insight into incentives within the food marketing chain.

3. Empirical implementation

3.1. Dimensions

A 3-stage food marketing chain is modelled, $s \in \{\text{Retail, Processing, Farm}\}$. The products i selected reflect their importance in the Danish food marketing chain $i \in \{\text{Pork, Chicken, Eggs, Milk, Beef}\}$. Attributes k selected reflect current policy and commercial developments and concerns in Denmark $k \in \{\text{Organic, Bacteria free, Identity preservation, Animal welfare}\}$.

3.2. Data

A set of indicative Danish cost and revenue data was assembled from several sources. Substantial simplification and aggregation within commodity sectors was used to compile and calibrate the data. A set of enterprise budgets was assembled for the farm production, processing and retail sale of each of the i products. The volumes used in the budgeting procedure were maintained. All monetary values are expressed in Danish kroner (DKK).

The budgets were subdivided as far as possible into constituent parts (e.g. sales of products and by-products, fuel and labour costs, etc). Fixed and variable components of costs were maintained separately to allow more targeted estimation of the impacts of provision on costs. For each attribute k, estimated impacts on costs for each product i were applied to relevant cost components. These are expressed as % increases in each of variable and costs. Retail price premia are derived from observed data, adjusted for by-product volumes and other factors such as rejections due to quality grading or inspection. Estimates of shares of price premia passed on by retailers are drawn from observed price patterns. Specification of scale and scope characteristics in cost functions drew on available research and the author's estimates.

Table 3.1 presents the data used in derivation of fixed and variable costs, and retail price premia. In these tables the logic flows from the left column (existing costs of production and existing retail prices) through the middle columns (% premia applied) to the right hand columns (derived premia used in the model specification).

Table 3.1. Data used in derivation of cost and price premia applied in models

Fixed costs of production			Fixed cost premium associated with each attribute				Derived fixed costs of provision				
		units	ORG	BA-FREE	I-PRES	AN-WF	ORG	BA-FREE	I-PRES	AN-WF	units
RET.PORK	0.50	DKK	NF*	45%	100%	NF	NF	0.23	0.50	NF	DKK
RET.CHKN	0.50	DKK	NF	45%	100%	NF	NF	0.23	0.50	NF	DKK
RET.EGGS	0.50	DKK	NF	150%	100%	NF	NF	0.75	0.50	NF	DKK
RET.MILK	0.50	DKK	NF	25%	100%	NF	NF	0.13	0.50	NF	DKK
RET.BEEF	0.50	DKK	NF	25%	100%	NF	NF	0.13	0.50	NF	DKK
PROC.PORK	3.64	DKK	NF	10%	10%	28%	NF	0.40	0.40	1.11	DKK
PROC.CHKN	2.40	DKK	NF	10%	25%	66%	NF	0.25	0.63	1.67	DKK
PROC.EGGS	3.00	DKK	NF	100%	100%	40%	NF	3.03	3.03	1.20	DKK
PROC.MILK	0.47	DKK	NF	28%	100%	11%	NF	0.13	0.47	0.05	DKK
PROC.BEEF	2.55	DKK	NF	10%	10%	11%	NF	0.35	0.35	0.39	DKK
FARM.PORK	8.18	DKK	42%	40%	10%	25%	5.73	5.45	1.36	3.41	DKK
FARM.CHKN	8.18	DKK	120%	40%	10%	60%	16.36	5.45	1.36	8.18	DKK
FARM.EGGS	4.78	DKK	192%	65%	100%	36%	9.46	3.20	4.93	1.77	DKK
FARM.MILK	2.00	DKK	23%	40%	100%	10%	0.46	0.81	2.02	0.20	DKK
FARM.BEEF	2.00	DKK	35%	40%	10%	10%	1.32	1.51	0.38	0.38	DKK

Variable costs of production			Variable cost premium associated with each attribute				Derived variable costs of provision				
		units	ORG	BA-FREE	I-PRES	AN-WF	ORG	BA-FREE	I-PRES	AN-WF	units
RET.PORK	14.20	DKK/kg	NF	100%	50%	NF	NF	14.20	7.10	NF	DKK/kg
RET.CHKN	11.25	DKK/kg	NF	100%	50%	NF	NF	11.25	5.63	NF	DKK/kg
RET.EGGS	12.50	DKK/kg	NF	100%	50%	NF	NF	12.50	6.25	NF	DKK/kg
RET.MILK	1.91	DKK/litre	NF	100%	50%	NF	NF	1.91	0.96	NF	DKK/litre
RET.BEEF	13.75	DKK/kg	NF	100%	50%	NF	NF	13.75	6.88	NF	DKK/kg
PROC.PORK	11.36	DKK/kg	NF	12%	5%	120%	NF	1.36	0.57	13.63	DKK/kg
PROC.CHKN	9.00	DKK/kg	NF	12%	10%	120%	NF	1.08	0.90	10.80	DKK/kg
PROC.EGGS	10.00	DKK/kg	NF	100%	100%	120%	NF	10.00	10.00	12.00	DKK/kg
PROC.MILK	1.53	DKK/litre	NF	10%	100%	120%	NF	0.15	1.53	1.84	DKK/litre
PROC.BEEF	11.00	DKK/kg	NF	12%	5%	120%	NF	1.32	0.55	13.20	DKK/kg
FARM.PORK	5.19	DKK/kg	0.4	10%	5%	18%	2.08	0.52	0.26	0.93	DKK/kg
FARM.CHKN	5.00	DKK/kg	55%	10%	25%	18%	2.75	0.50	1.25	0.90	DKK/kg
FARM.EGGS	5.19	DKK/kg	111%	65%	100%	28%	5.76	3.37	5.19	1.45	DKK/kg
FARM.MILK	1.07	DKK/litre	17%	10%	100%	18%	0.18	0.11	1.07	0.19	DKK/litre
FARM.BEEF	6.60	DKK/kg	38%	10%	5%	28%	2.51	0.66	0.33	1.85	DKK/kg

*NF indicates non-feasible provision for a given attribute at a given stage.

…to be continued

Table 3.1. (continued)

Retail prices for each product			Retail price premium associated with each attribute				Derived retail price premia for each attribute				
		units	ORG	BA-FREE	I-PRES	AN-WF	ORG	BA-FREE	I-PRES	AN-WF	units
RET.PORK	60.00	DKK/kg	25%	12%	10%	15%	15.00	7.20	6.00	9.00	DKK/kg
RET.CHKN	50.00	DKK/kg	30%	10%	10%	15%	15.00	5.00	5.00	7.50	DKK/kg
RET.EGGS	15.00	DKK/kg	30%	18%	0%	25%	4.50	2.70	0.00	3.75	DKK/kg
RET.MILK	8.00	DKK/litre	17%	10%	0%	6%	1.36	0.80	0.00	0.48	DKK/litre
RET.BEEF	50.00	DKK/kg	18%	8%	10%	12%	9.00	4.00	5.00	6.00	DKK/kg

3.3. Scenarios

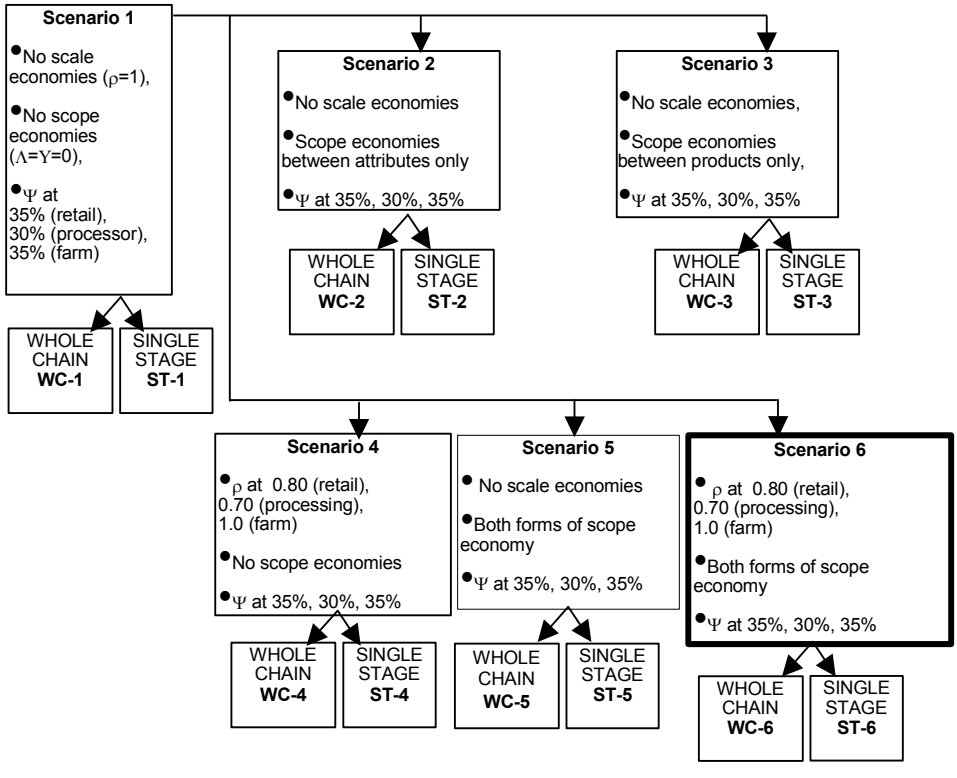
Whole chain vs single stage

For every scenario, paired runs are used to compare solutions from objective functions (4) and (5). For each scenario, the notation "WC" is used to denote the whole chain model, and "ST" the single stage model.

Technology specifications

Scenarios 1-6 feature combinations of Υ^s_{il}, Υ^s_{jk}, Λ^s_{il}, Λ^s_{jk} and ρ^s_{ik} to examine the impacts of the various forms of economies of scope, and of scale. Scenario 1 is used as a baseline against scenarios 2-6.

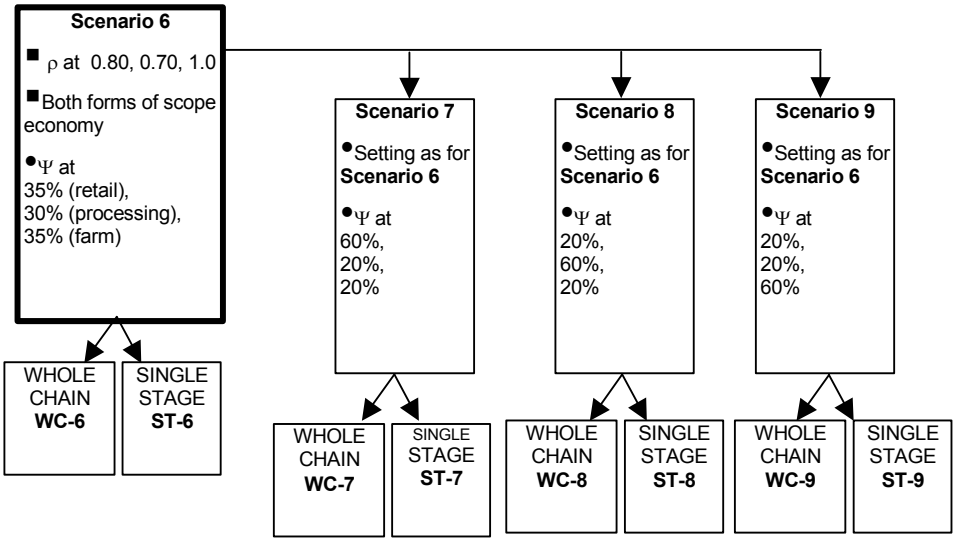
Figure 3.1. Scenarios examining technology specifications



Price premium specifications

A range of specifications of Ψ_{ik}^{s} is used to provide scenarios where the 3 stages of the food marketing chain receive different shares of the price premium p_{ik}^{R}. Scenario 6 is used as a baseline against scenarios 7-9.

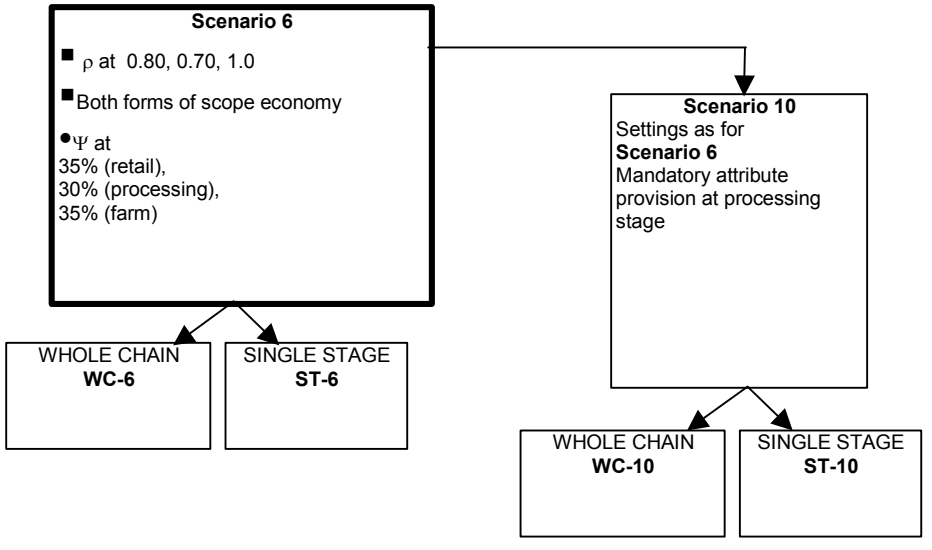
Figure 3.2. Scenarios examining price premium specifications



Mandatory attribute provision

Mandatory provision of an attribute is enforced by exogenous specification of $A_{ik}^{s}=1$ for the stage, product and attribute in question. The attribute "bacteria free" for eggs was chosen as an example because it was not featured in any solution investigated during the model runs. The processor stage was arbitrarily chosen as the mandated provider of the attribute. Scenario 6 is used as a baseline against scenario 10.

Figure 3.3. Scenarios examining mandatory attribute provision



4. Results

4.1. Response to changes in technology specifications

Attribute provision

Introduction to the model of scale and scope economies (scenarios 1-6) increases the number of attributes provided, and increases the profits accruing to the entire food marketing chain. This result holds for both the whole chain model and the single-stage model, and in both cases the impacts of scope are far greater than those of scale.

With no economies of scale and scope the whole chain model (scenario WC-1) delivers 14 attributes: 6 at processing stage; 8 at farm stage; and none at retail stage (table 4.1). In contrast, the single stage model delivers only 6 attributes: 2 at processing stage and 4 at farm stage (table 4.2). This difference reflects the internalisation of the incentives for provision: the whole chain model delivers attributes so long as total chain profitability is increased; the single stage model only where it is profitable for the providing stage to do so. The attributes provided in the whole chain model, although not in the single stage model, can result in losses to the providing stage. Those losses are offset by profits at other stages (the process of internalisation), and the re-allocation of the remaining chain profits allow for potential compensation within the chain. The extent and practical implementation of this compensation is addressed further below.

In the whole chain model (table 4.1) economies of scope deliver an additional 2 attributes, (scenario WC-2 and scenario WC-3) over the baseline scenario (WC-1). However, the two different forms of economies of scope deliver the new attributes at different stages: economies of scope between attributes (scenario WC-2) delivers two new attributes for chicken (organic and animal welfare) at farm stage and identity preservation in beef at processing stage (a switch from farm provision to processor provision where it accompanies identity preservation by processors for other meats). Economies of scope between attributes raise chain profits by 22% (from 62.531 to 76.648). Economies of scope between products (scenario WC-3) raises chain profits only 10%, and sees identity preservation in beef revert to farm stage.

In the single stage model (table 4.2), economies of scope have a more profound effect, and the two forms of economies of scope (scenario ST-2 vs. scenario ST-3) yield

markedly different provision outcomes. Economies of scope between attributes (scenario ST-2) delivers 3 new attributes: farm provision of organic pork and organic beef, and processor provision of identity-preserved chicken. In contrast to the whole chain model, identity preservation for beef remains at farm stage when economies of scope between attributes are introduced. Economies of scope between products in the single stage model (scenario ST-3) results in organic milk and organic beef being provided together at farm stage, and bacteria-free beef is provided at farm stage to accompany (table 4.2). Bacteria-free beef is expected to be more expensive to provide where beef is also produced with animal welfare and organic attributes, implying a negative impact of economies of scope between attributes: hence its appearance in the single-stage model only in scenario ST-3, which features only economies of scope between products.

In the single-stage model, no provision switches occur between stages due to economies of scope. Economies of scope raise chain profits by 83% (scenario ST-2, economies of scope between attributes) and 53% (scenario ST-3, economies of scope between products). Notably, economies of scope between products (scenario ST-3) delivers more attributes but is significantly less profitable than economies of scope between attributes (scenario ST-2).

Economies of scale have quite different impacts on the whole chain model (table 4.1, WC-4) than on the single stage model (table 4.2, ST-4). In the whole chain model, no additional attributes are provided over scenario 1, there is no change in the stage at which provision occurs, and profits rise very slightly. In the single stage model, identity preserved chicken is introduced at the processing stage, but no switching of provision between stages occurs. Chain profits rise from 35.129 to 39.875 (an increase of 13%).

The introduction of both forms of economies of scope simultaneously (scenario 5) yields 16 attributes in the whole chain model, the same as each of the forms of economies of scope individually (WC-2 and WC-3), and increases profits 37% over scenario WC-1. In the single stage model, scenario ST-5 delivers 11 attributes, more than in either of ST-2 and ST-3, and the stage-configuration of provision is quite different to that in scenarios ST-1 to ST-4. Moreover, in the single stage model access to both forms of economies of scope (ST-4) almost doubles chain profits (from 35.129 to 70.001), compared with a 37% increase in the whole chain model. For both models, the simultaneous introduction of economies of scale with economies of scope (WC-6 and ST-6) does not alter the provision pattern from those in scenario 5.

Table 4.1. Whole chain model: response to changes in technology specification

	WC-1	WC-2	WC-3	WC-4	WC-5	WC-6
Chain profits	62.531	76.648	69.065	62.802	85.753	86.046
Attribute provision	14	16	16	14	16	16
Retail provision	0	0	0	0	0	0
Processing provision	6	7	6	6	7	7
Farm provision	8	9	10	8	9	9
ORG-PORK*	F	F	F	F	F	F
ORG-CHKN		F	F		F	F
ORG-EGGS						
ORG-MILK	F	F	F	F	F	F
ORG-BEEF	F	F	F	F	F	F
BA-FREE-PORK	W	W	W	W	W	W
BA-FREE-CHKN	W	W	W	W	W	W
BA-FREE-EGGS						
BA-FREE-MILK	W	W	W	W	W	W
BA-FREE-BEEF	W	W	W	W	W	W
I-PRES-PORK	W	W	W	W	W	W
I-PRES-CHKN	W	W	W	W	W	W
I-PRES-EGGS						
I-PRES-MILK						
I-PRES-BEEF	F	W	F	F	W	W
AN-WF-PORK	F	F	F	F	F	F
AN-WF-CHKN		F	F		F	F
AN-WF-EGGS	F	F	F	F	F	F
AN-WF-MILK	F	F	F	F	F	F
AN-WF-BEEF	F	F	F	F	F	F

* ”F” = attribute provided at Farm stage; ”W” at Processing stage; “R” at Retail stage

Table 4.2. Single stage model: response to changes in technology specification

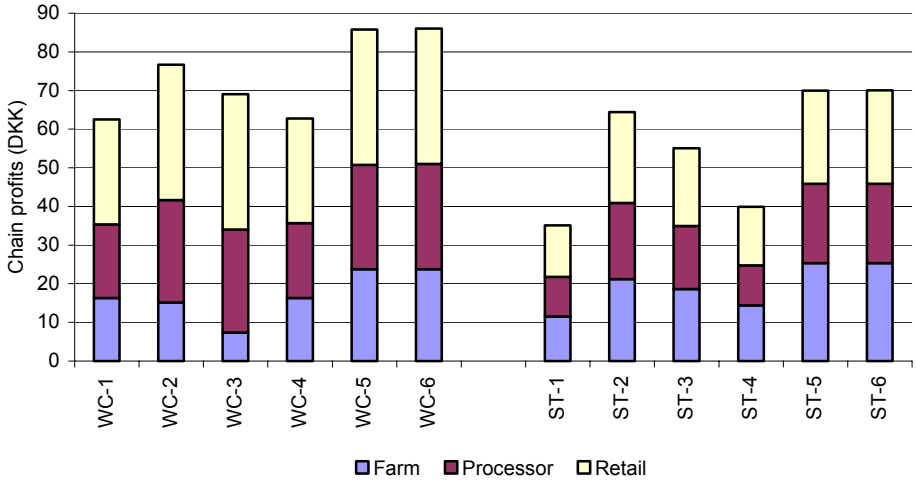
	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6
Chain profits	35.129	64.417	55.091	39.875	70.001	70.070
Attribute provision	6	9	10	7	11	11
Retail provision	0	0	0	0	0	0
Processing provision	2	3	3	3	3	3
Farm provision	4	6	7	4	8	8
ORG-PORK		F			F	F
ORG-CHKN						
ORG-EGGS						
ORG-MILK			F		F	F
ORG-BEEF		F	F		F	F
BA-FREE-PORK	W	W	W	W	W	W
BA-FREE-CHKN	W	W	W	W	W	W
BA-FREE-EGGS						
BA-FREE-MILK						
BA-FREE-BEEF			F			
I-PRES-PORK	F	F	F	F	F	F
I-PRES-CHKN		W	W	W	W	W
I-PRES-EGGS						
I-PRES-MILK						
I-PRES-BEEF	F	F	F	F	F	F
AN-WF-PORK	F	F	F	F	F	F
AN-WF-CHKN						
AN-WF-EGGS						
AN-WF-MILK					F	F
AN-WF-BEEF	F	F	F	F	F	F

Distribution of chain profits

The distribution of profits arising from technology-related scenarios is presented in figure 4.1. In the whole chain model (WC-1 to WC-6 in figure 4.1), retailers retain a significant share of chain profits under all scenarios, while farm and processors' shares of profits fluctuate. In the single stage model (ST in figure 4.1), the shares of profits are much more consistent across scenarios. This difference arises because in the single stage model no firms make losses, so provision in response to economies of scope adds to profits from provision of both old and new attributes.

In the whole chain model, losses from provision at one stage can be added to by further provision, so long as aggregate chain profits rise in the process. Scenarios that add attributes (WC-3 compared to WC-1 and WC-2) may involve burdening one stage (in this case the farm stage) with increasing losses. However, for non-providing stages profits always rise with provision by other stages, resulting in a rise in the share of chain profits accruing to non-providing stages. This demonstrates the free-riding incentives discussed above.

Figure 4.1. Distribution of chain profits: response to technology specification



4.2. Response to change in price premium specifications

Attribute provision

In the whole chain model, re-specification of the allocation of shares of price premia amongst stages of the food marketing chain leaves attribute provision unaffected, at 16 attributes, of which 7 at processing stage and 9 at farm stage (table 4.3).

In contrast, the single stage model's pattern of attribute provision (see table 4.4) is highly sensitive to the allocation of price premium. Scenario ST-7 (where 60% of the price premium is retained at the retail stage) features provision of one attribute at retail stage, 2 at processing and 5 at farm stage, for a total of 8. Scenario ST-8 (60% of price premium to the processor) is dominated by the processing stage (7 of 11 attributes provided). Scenario ST-9 (60% of premium to the farm stage) features 13 of a total 14 attributes being provided at farm stage.

These results further demonstrate the divergent incentives in the two models of chain behaviour. Clearly, internalising the free-rider effects (using the whole chain model) generates the larger number of attributes, but a real-world outcome of this type requires substantial compensation to providing stages from other stages. Putting those compensation mechanisms in place first (i.e. by re-aligning shares of price premia in the single stage model) clearly encourages provision, but that provision occurs only at stages that have access to the price premia. Clearly, *ex post* compensation has the capacity deliver more attributes and higher chain profits that does *ex ante* specification of incentives. However, firms providing attributes need to be assured of receiving the compensation, in appropriate amounts, before provision can occur.

Table 4.3. Whole chain model: response to changes in shares of price premium

	WC-6	WC-7	WC-8	WC-9
Chain profits	86.046	74.340	80.426	101.497
No. Atts	16	16	16	16
Retail provision	0	0	0	0
Processing provision	7	7	7	7
Farm provision	9	9	9	9
ORG-PORK	F	F	F	F
ORG-CHKN	F	F	F	F
ORG-EGGS				
ORG-MILK	F	F	F	F
ORG-BEEF	F	F	F	F
BA-FREE-PORK	W	W	W	W
BA-FREE-CHKN	W	W	W	W
BA-FREE-EGGS				
BA-FREE-MILK	W	W	W	W
BA-FREE-BEEF	W	W	W	W
I-PRES-PORK	W	W	W	W
I-PRES-CHKN	W	W	W	W
I-PRES-EGGS				
I-PRES-MILK				
I-PRES-BEEF	W	W	W	W
AN-WF-PORK	F	F	F	F
AN-WF-CHKN	F	F	F	F
AN-WF-EGGS	F	F	F	F
AN-WF-MILK	F	F	F	F
AN-WF-BEEF	F	F	F	F

Table 4.4. Single stage model: response to changes in shares of price premium

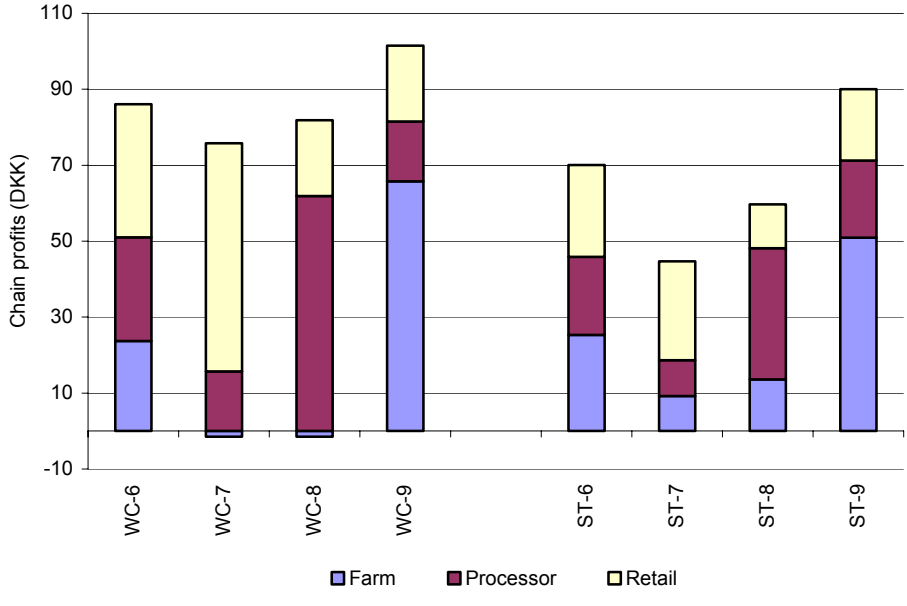
	ST-6	ST-7	ST-8	ST-9
Chain profits	70.070	44.650	59.650	90.057
No. Atts	11	8	11	14
Retail provision	0	1	0	0
Processing provision	3	2	7	1
Farm provision	8	5	4	13
ORG-PORK	F			F
ORG-CHKN				F
ORG-EGGS				
ORG-MILK	F			F
ORG-BEEF	F	F	F	F
BA-FREE-PORK	W	W	W	W
BA-FREE-CHKN	W		W	
BA-FREE-EGGS				
BA-FREE-MILK			W	
BA-FREE-BEEF			W	F
I-PRES-PORK	F	W	W	F
I-PRES-CHKN	W	R	W	F
I-PRES-EGGS				
I-PRES-MILK				
I-PRES-BEEF	F	F	W	F
AN-WF-PORK	F	F	F	F
AN-WF-CHKN				F
AN-WF-EGGS				F
AN-WF-MILK	F	F	F	F
AN-WF-BEEF	F	F	F	F

Distribution of chain profits

In the whole chain model, the distribution of chain profits follows the allocation of price premia in the chain. This means that (see figure 4.2) WC-7 features the majority of profits accruing to retailers, in WC-8 the majority accrues to processors, and in WC-9 it goes to farmers. Notably, WC-7 and WC-8 feature negative profits at the farm stage, despite farmers' participation in attribute provision.

In the single stage model (ST-6-ST-9 in figure 4.2), the shares of profits accruing to each stage are far more stable: the major share of profits still accrues to the stage with the major share of price premia, but no stage suffers negative profits. In the single stage model, the share of profits accruing to each stage is more closely aligned with the share of provision than with the share of price premium: stages will provide attributes only if they get paid to do so.

Figure 4.2. Distribution of chain profits: response to price premium allocation



4.3. Response to mandatory provision

Attribute provision

In the scenario where provision is mandated (WC-10 and ST-10), both models deliver reduced profits with no change in configuration of provision amongst stages in comparison with scenario 6 (table 4.5), aside from the provision of bacteria-free eggs at the processing stage.

Table 4.5. Response to mandatory processor provision of bacteria free eggs

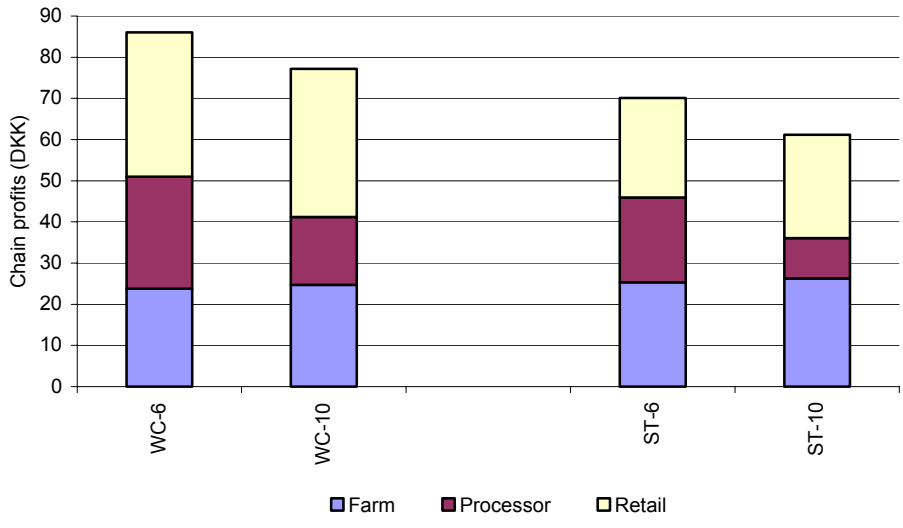
	WC-6	WC-10	ST-6	ST-10
Chain profits	86.046	77.144	70.070	61.168
Attribute provision	16	17	11	12
Retail provision	0	0	0	0
Processing provision	7	8	3	4
Farm provision	9	9	8	8
ORG-PORK	F	F	F	F
ORG-CHKN	F	F		
ORG-EGGS				
ORG-MILK	F	F	F	F
ORG-BEEF	F	F	F	F
BA-FREE-PORK	W	W	W	W
BA-FREE-CHKN	W	W	W	W
BA-FREE-EGGS*		**W**		**W**
BA-FREE-MILK	W	W		
BA-FREE-BEEF	W	W		
I-PRES-PORK	W	W	F	F
I-PRES-CHKN	W	W	W	W
I-PRES-EGGS				
I-PRES-MILK				
I-PRES-BEEF	W	W	F	F
AN-WF-PORK	F	F	F	F
AN-WF-CHKN	F	F		
AN-WF-EGGS	F	F		
AN-WF-MILK	F	F	F	F
AN-WF-BEEF	F	F	F	F

***BOLD** figures indicate mandatory provision

Distribution of chain profits

In both models, mandatory provision reduces profits at the providing stage (in this case, processing), and raises profits at the other two stages (figure 4.3).

Figure 4.3. Distribution of chain profits: response to mandatory provision



4.4. Examples of dual variable values

Explanatory note

The values of the LaGrangian multipliers λ_{ik}^{s} and υ_{ik}^{s} address attributes that are not provided. They measure the loss that would be incurred at each stage of the food marketing chain **if the attribute had been provided by firms at that stage** in each scenario. Recall that λ_{ik}^{s} and υ_{ik}^{s} refer to the whole chain and single stage models, respectively.

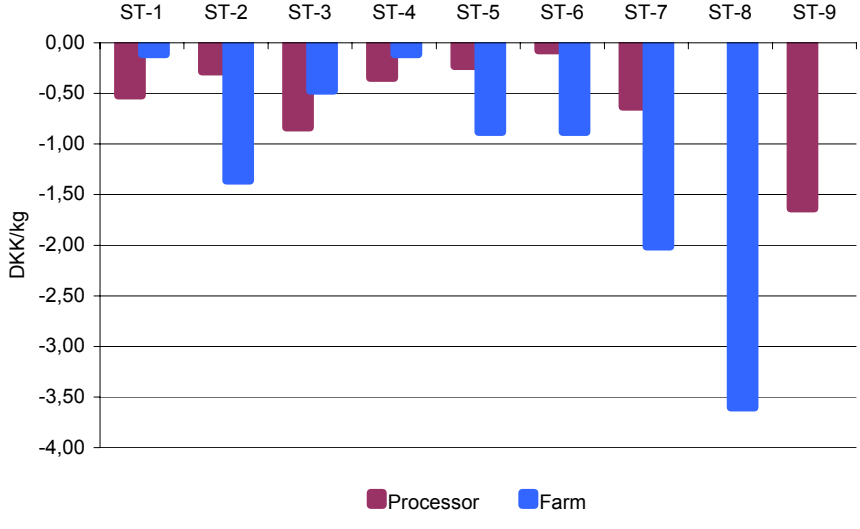
In the event that a particular product attribute is considered socially desirable, but is not provided by firms in response to market incentives, then the absolute value of the LaGrangian multiplier can be interpreted as the subsidy necessary to invoke provision. Space prevents presentation of all values generated for LaGrangian multipliers, so a selection is presented here.

Provision of bacteria-free beef at farm and processing stages

The single stage values $\upsilon^{FARM}_{BEEF,\,BA-FREE}$ and $\upsilon^{PROCESSOR}_{BEEF,\,BA-FREE}$ for ST-1 to ST-9 are shown in figure 4.4. Note that in ST-1 to ST-6, the values of the LaGrangian multiplier at each stage vary considerably, and their relative magnitudes at farm and processing stage reverse themselves several times. In ST-8 the attribute is provided by processors, and in ST-9 by farmers, so no corresponding values for $\upsilon^{FARM}_{BEEF,\,BA-FREE}$ and $\upsilon^{PROCESSOR}_{BEEF,\,BA-FREE}$ are shown in figure 4.4.

These results suggest that (i) provision of bacteria-free beef will not occur unless the share of retail price premium substantially favours the providing stage (see ST-7, ST-8 and ST-9), and (ii) that the stage at which provision is at lowest cost can depend on the availability of economies of scale and scope (ST-1 to ST-6).

Figure 4.4. LaGrangian multiplier values for bacteria-free beef products



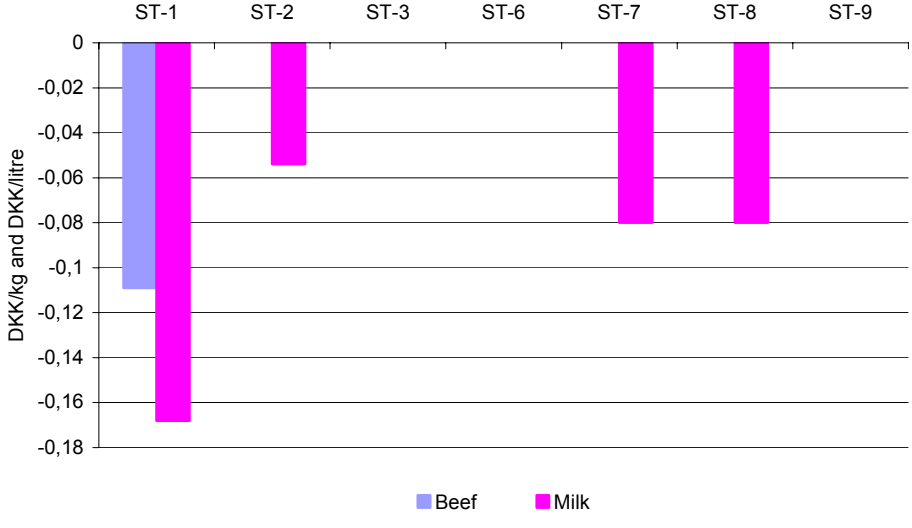
A consequence of (ii) is that if a subsidy were to be provided to ensure provision, the cheapest subsidy would be targeted at the farm stage in cases where economies of scope appear between attributes (ST-2), but at the processing stage where economies of scope appear between products (ST-3). Where both forms of economies of scope

apply, and economies of scale are available, the cheapest subsidy would be targeted at the processor.

Provision of organic attributes at farm stage for beef and/or milk products

For practical reasons, provision of organic product attributes is likely to be confined to the farm stage. Organic milk and organic beef are provided in scenarios 3, 6 and 9 (which is why figure 4.5 does not display a value for those scenarios). The model results suggest that economies of scope between products (ST-3 and ST-6), and favourable shares of price premium at farm level (ST-9) favour organic beef and milk production at farm level.

Figure 4.5. LaGrangian multiplier values for organic milk and beef at farm level



The results in figure 4.5 can be interpreted in terms of the necessary subsidy to ensure provision. With no cost advantages (economies of scale or scope) the necessary subsidy to farmers is about 0.11 DKK/kg of beef and 0.17 DKK/kg of milk. In the presence of economies of scope between attributes (scenario 2), organic beef is provided but not organic milk: a subsidy of 0.05 DKK/kg of milk would be required for organic milk to be provided as well as organic beef.

Where the farm stage's share of the retail price premium for organic milk and organic beef is only 20% (scenarios 7 and 8), the results indicate that organic beef would be provided, but a subsidy of about 0.08 DKK/kg of milk would be necessary for organic milk to be provided as well. Where the farm stage receives 60% of the retail price premium, both organic milk and organic beef are provided at farm stage.

Non-provision of bacteria-free eggs

In the scenarios investigated using both models, bacteria-free eggs is one of the product attributes not provided in model output. This is a consequence of the data used: sufficient incentives for provision (at any stage) do not exist. Table 4.6 presents selected values for υ_{ik}^{s} and λ_{ik}^{s} from scenarios associated with technologies employed (scenario 1) and the allocation of price premium amongst stages (scenarios 6-9).

Table 4.6. Lagrangian multiplier values for provision of bacteria-free eggs

	Single stage model (ST)		Whole chain model (WC)	
	$\upsilon_{EGGS,\,BA-FREE}^{PROCESSOR}$	$\upsilon_{EGGS,\,BA-FREE}^{FARM}$	$\lambda_{EGGS,\,BA-FREE}^{PROCESSOR}$	$\lambda_{EGGS,\,BA-FREE}^{FARM}$
	DKK/kg			
scenario 1	-12.31	-5.74	-10.39	-3.94
scenario 6	-10.82	-7.61	-8.90	-5.84
scenario 7	-11.09	-8.02	-8.92	-5.86
scenario 8	-10.00	-8.02	-8.91	-5.85
scenario 9	-11.09	-6.91	-8.88	-5.82

Results from both models indicate that it is always more expensive for the processing stage to provide bacteria-free eggs than it is for the farm stage. An alternative interpretation is that if a subsidy were to be paid, it would always be cheaper to subsidise the farm stage than the processing stage.

The magnitude of the single stage model's values (υ_{ik}^{s}) are always higher than the whole chain model's (λ_{ik}^{s}) because the whole chain model takes into account benefits at non-providing stages. Should a mandating authority consider taxation of one or more stages of the marketing chain in order to redistribute benefits arising from mandatory provision, then the amount of the tax is correctly measured by $\lambda_{ik}^{s} < \upsilon_{ik}^{s} \;\forall\, s$. In a practical sense, the stages of the food marketing chain would then need to collaborate on the form and mechanism of redistribution.

The reported increase in the magnitude of the farm stage LaGrangian multiplier between scenario 1 and scenario 6 (columns 2 and 4 of table 4.4) reflect the impacts of economies (or in this case, diseconomies) of scope: provision of bacteria-free eggs at farm stage is more expensive where organic or animal welfare attributes are also to be provided in egg production. Notably, the opposite effect is observed at processing stage (columns 1 and 3): industrial processes can be expected to offer synergies for diversified lines of processed product, allowing a cost saving between scenarios 1 and 6. These results show that the identification of the least-cost provider and the sources of compensatory taxes will be different in different technological and provision situations.

4.5. Compensation between stages

Explanatory note

The whole chain model delivers attributes in circumstances where, at the margin, whole-chain revenues exceed whole-chain costs. Unlike in the single stage model, provision in the whole chain model can occur despite a loss accruing to the providing stage. Calculations on the endogenous variables allow identification of those losses, and of the potential for compensation amongst stages of the food marketing chain.

Examination of the provision of organic chicken

Table 4.7 presents the profits calculated from scenario WC-6. Losses (shown in **bold**) can be identified at the processing stage (0.02 DKK for bacteria-free milk and 0.08 DKK for bacteria-free beef), and at farm stage (5.03 DKK for organic chicken, 1.40 DKK for animal welfare attributes for chicken and 0.65 DKK for animal welfare attributes for eggs.

Table 4.7. Scenario WC-6: Table of profits by stage, product and attribute

	Attribute			
Stage. product	ORG	BA-FREE	I-PRESS	AN-WF
		DKK		
Ret. Pork	5.25	2.52	2.10	3.15
Ret. Chicken	5.25	1.75	1.75	2.63
Ret. Eggs				1.31
Ret. Milk	0.48	0.28		0.17
Ret. Beef	3.15	1.40	1.75	2.10
Proc. Pork	5.00	0.86	1.32	3.00
Proc. Chicken	4.74	0.40	0.44	2.37
Proc. Eggs				1.14
Proc. Milk	0.41	**-0.02**		0.14
Proc. Beef	3.75	**-0.08**	1.32	2.50
Farm. Pork	2.06	4.20	3.50	2.40
Farm. Chicken	**-5.03**	2.92	2.92	**-1.40**
Farm. Eggs				**-0.65**
Farm. Milk	0.13	0.28		0.09
Farm. Beef	2.90	2.64	3.30	3.48

Using organic chicken as an example, the sum of retail profits (5.25 DKK) and processing profits (4.74 DKK) is 9.99 DKK. If compensation were paid to the farm stage (which loses 5.03 DKK) by the other two stages, a surplus of 4.96 DKK is still available to be divided between one, two, or three stages. The form that compensation might take is not pursued further here, but obviously might appear as a higher share of price premia or as one or more shared cost items, enabled by communication of costs, benefits and other information amongst stages.

Table 4.8 presents model output for other scenarios concerning provision of organic chicken. In WC-6 (described above) the allocation of retail price premium is 30%, 35%, 30% to each of retail, processing and farm stages. In WC-7 and WC-8, those shares are skewed in favour of the retail and processing stages, respectively. Table 4.8 presents the differential profit levels achieved by those two stages, and the loss incurred at farm stage (8.78 DKK in both cases).

The bottom row of table 4.8 measures the surplus left over after compensation of the farm stage for unprofitable provision. Notably, the surplus is much higher in the case of equitable premium shares (4.96 DKK in WC-6) than in either of the cases where premium shares greatly favour non-providing stages (3.38 and 3.70 DKK).

Table 4.8. Organic chicken: compensation under conditions of changed allocation of price premium

	WC-6	WC-7	WC-8
		DKK	
Ret. Chicken	5.25	9.00	3.00
Proc. Chicken	4.74	3.16	9.47
Farm. Chicken	-5.03	-8.78	-8.78
Surplus after compensation	4.96	3.38	3.70

5. Discussion and conclusions

5.1. Overview

Provision of quality attributes offers incentives for Danish food industry firms to co-ordinate up and down the food marketing chain. Such co-ordination also offers opportunities for greater efficiency in public policies and enhanced public-private partnership. To some extent these improvements have been demonstrated in the case of Salmonella in the Danish pork, chicken and shell eggs sectors. This paper proposes a new method of quantifying the costs and benefits of alternative provision and funding mechanisms, when provision of food safety is integrated with other provision activities and is placed in the context of price manipulation through market power.

Beyond food safety, three other attributes (organics, trace-ability and animal welfare) of current interest in Denmark are examined here. Patterns of provision within the chain are seen to be deeply affected by changes in incentives at each stage and for the whole chain, and result in large changes in the size and allocation of chain profits from provision.

A mathematical programming model is used to examine provision of quality attributes in the Danish food marketing chain. Impacts of alternative provision technologies are examined, as are implications of reallocations of shares of retail price premium for each product attribute. Data used in the model are indicative estimates of costs, cost interactions, and price premia.

In recognition of the potential for externality and free-riding in the food marketing chain, two forms of the model are used:

- a "single stage" model in which firms at individual stages of the food marketing chain make attribute provision decisions on the basis of profitability at their own stage; and
- a "whole chain" model in which maximising profits in the entire food marketing chain is the objective, with provision allocated to the lowest cost provider.

All scenarios featured paired runs of the model: the whole chain and the single stage approaches described above. Results obtained from the model include provision,

profitability and derived dual variables (LaGrangian multipliers). These are able to be interpreted in terms of potential subsidization from government and between-stage compensation by agents in the food marketing chain.

5.2. Main results

Technological specifications

The whole chain model provides a larger number of attributes than does the single stage model, in all scenarios investigated. This is because the whole chain model fully internalises all the externalities and potential transfer payments within the food marketing chain.

In both models, attribute provision increases as cost advantages are introduced. This effect is more pronounced in the single stage model, because cost re-specifications directly affect incentives for providing stages. Economies of scale and scope are examined in some depth. At the farm stage, economies of scope are more likely to occur between products (e.g. organic production of both beef and milk) than between attributes (e.g. beef that is both bacteria-free and produced organically). However, at the processing stage the reverse may be true: diversified lines of the same product may be more profitable than provision of the same attribute across a whole range of products.

These effects are demonstrated in the model: the single stage model is particularly sensitive to the form of economies of scope: presented here as being between attributes (*k*-form) or between products (*i*-form). The single stage model delivers more attributes in the presence of *i*-form economies of scope than it does with *k*-form economies of scope. However, profits are higher with *k*-form economies of scope. With both forms of economies of scope, the single stage model provides still more attributes, and profits increase over the baseline scenario.

The whole chain model delivers the same number of attributes regardless of the form of economies of scope. The *k*-form and *i*-form scenarios deliver different allocations of provision amongst stages, because the cheapest provider is always selected by the whole chain model. Profits are higher with *i*-form economies of scope, but the differences are much less than is the case in the single stage model.

The impact of technological specification on the distribution of profits in the food marketing chain is also different between the two models. The whole chain model (which features higher chain profits) delivers outcomes where the stages providing the attributes receive a low proportion of chain profits. Conversely, in the single stage model the stages providing the attributes retain a significant share of chain profits.

Allocation of price premia

In the whole chain model, provision of attributes is insensitive to the allocation of the retail price premium amongst stages. Chain profits, however, behave in a complex manner in the whole chain model as premium shares are re-specified. Chain profits are maximised when the farm stage receives the highest share of price premiums: this is because costs of provision are able to be offset by increased revenues while the retail and processing stages have fewer opportunities for provision. Allocation of large shares of price premium to retail and processing stages results in losses at the farm stage, which form the basis for compensation mechanisms (see below).

In the single stage model, the number of attributes provided, and the stages at which provision occurs, are highly sensitive to the shares of price premia allocated to the three stages. Skewing of the share of price premia in favour of the providing stages (processing and farm) increases the number of attributes provided and increases chain profits. In addition, the pattern of provision in the single stage model is extremely sensitive to premium allocation, delivering attributes at retail and processing stages in scenarios where those stages respectively receive high shares of the retail price premium. Allocation of 60% of the price premium to the farm stage results in 13 of 14 attributes being provided at farm stage. Overall, the single stage model allows for a more equitable distribution of chain profits from any given scenario, than does the whole chain model.

5.3. Commercial implications

Discrepancy between whole chain and single stage models

Neither model presented here is a complete and true interpretation of incentives in the food marketing chain. In any multiple-stage food marketing chain without full vertical integration the whole chain model is unlikely to apply, and attribute provision is

likely to follow the single stage model. On the other hand, in any case where provision occurs it generates externalities that are fully captured only by the whole chain model.

The key commercial question is whether the whole chain model's outcomes can be mimicked by the single stage model in the context of communication and incentive mechanisms amongst stages. The key policy question is what role government might play to bring about the whole-chain outcome in the case where it is socially desirable.

Key results concerning profitability

The results presented here reflect the principle that chain profits are increased by provision at the lowest-cost stage of the food marketing chain. Moreover, profits and provision are increased further in scenarios where price premia are allocated towards the stages providing the attributes. These two outcomes reinforce the result achieved elsewhere, that chain profits can be increased by improved information-sharing within the food chain. In particular, the sharing of information about costs of provision and the sizes and shares of price premia, can increase chain profits.

Because of the apparent influence of economies of scale and scope on the costs of attribute provision, information sharing would ideally feature data on a broad spectrum of products and product groups, and the identification of synergies (and non-synergies) that may lower (or raise) costs at each stage of the food marketing chain.

Examples presented here demonstrate that the lowest-cost stage for provision can change with the change in technology (e.g. provision of bacteria-free beef switches between stages), and that combinations of products offer significant cost reductions (e.g. organic milk and beef at farm stage) as well as cost increases (e.g. bacteria-free eggs at farm level). Notably, results indicate that bacteria-free eggs are cheaper to provide in combination with other attributes and products at processing stage, but more expensive at farm stage.

Compensation between stages

The results from the whole chain model indicate that there is significant scope for compensation of providing stages by other stages of the food marketing chain. A notable result is that the available net surplus (after compensation has been paid) is

higher in scenarios with an equitable allocation of price premia, than in scenarios where the price premium is largely retained by retailers or processors.

The example of organic chicken is presented in some detail. The single stage model does not deliver this product attribute, but the whole chain model does so at an apparent loss to farmers providing the attribute. A reduction in the retail share of the price premium results in a post-compensation gain to the retailer, provided that the stages of the food marketing chain can successfully negotiate and implement compensation mechanisms.

Funding and allocation of taxes

Where an industry funds its own attribute provision (voluntarily or subject to a mandate), the whole chain model appropriately identifies costs to the entire chain, which is equivalent to a tax on the industry. Efficient re-allocation of self-imposed taxes (i.e. industry levies) would be guided by the model's outcomes.

This provides industry with insight into costs and benefits of alternative courses of action when faced with the possibility of mandatory provision. Bacteria-free eggs are taken as an example, where the model's dual variables identify costs both to the whole chain and to individual stages. These values can be directly compared to existing and proposed levies and other forms of taxation.

5.4. Policy implications

Mandatory provision

The model results show that the costs of mandatory provision are borne by the provider in the sense of raised costs, but are not shared by the other stages of the food marketing chain. It is possible that a providing stage would benefit from economies of scope between products or between attributes as a consequence of mandatory provision, but the model scenarios examined here did not yield such a result.

As shown repeatedly in this report, the costs to the food marketing chain are heavily influenced by the technologies being applied at each one of its stages. The example of bacteria-free beef is examined in some detail, to show that the cheapest provider may be either the farm or processing stage, depending on the presence and nature of

economies of scale and scope. Moreover, the impacts of provision can be magnified by unfavourable shares of price premia, which will increase profits accruing to other stages of the food marketing chain. In the case of bacteria-free eggs, the costs to the food chain as a whole, and to the providing firms, are affected quite differently by technology: provision with economies of scope incurs extra costs at farm stage but cost savings at processing stage.

Subsidy

The results presented in this paper identify, across a range of scenarios, products and attributes, the subsidy necessary to evoke attribute provision. In some cases, its results are surprising (albeit dependent on data): subsidies for provision of bacteria-free eggs would always be cheaper to pay to farmers, despite mandates and accompanying subsidies frequently being applied at processing stage. In other cases, the model demonstrates the information discrepancy inherent in any subsidy programme: the stage at which the cheapest subsidy might be paid is highly dependent on cost and revenue data that is likely to be known only by commercial agents.

5.5. Limitations and possible extensions

Data

The data used in this paper are, at best, estimates. The analysis is intended to mimic the influence of specific variables and parameters on attribute provision, relative to a baseline, rather than to accurately estimate costs and benefits of change in the food marketing chain. The model, and the analysis presented here, would benefit from improved data, particularly from commercial firms.

Applications

The model addresses a multi-sector problem at a high level of aggregation. The model is possibly better suited to analysis of a set of clearly-defined and closely-related products. The model has the capacity for within-factory or within-firm analysis of tightly-grouped products, or other more focused analyses (e.g. of regions or single sectors).

Non-provision costs

The model would benefit from the inclusion of costs to the marketing chain other than those of provision. In particular, costs of preservation of an attribute and generation and transmission of signals have not been addressed here. They would make excellent extensions to the model.

Mix of endogeneous and exogenous variables

The analysis is partial-equilibrium in nature. It ignores market-clearing impacts, particularly those associated with the dilution of attributes' price premia as a consequence of supply response across a large number of firms. This limitation might be overcome by introducing decay mechanisms for price premia that are dependent on aggregate supply elasticities. Full endogenization of prices would be difficult in the presence of exogenously-determined transmission of shares of price premia. Endogenous premia might also be offered as an extension of the model.

Where market-clearing mechanisms were used, a further extension becomes possible, in generating welfare measures beyond the profitability of isolated firms. Consumer and producer surplus, for example, could be derived from demand and supply specifications. In the case of large retail firms' aggregate value added might be employed as a welfare measure.

Risk

Consideration of risk is a further desirable extension of the model. The certainty with which price premia occur, and cost advantages can be captured, offer one avenue of extension. Another is the risks inherent within-chain negotiation: the certainty with which agents can expect to receive proscribed shares of price premia. A third is the incorporation of each stage's risk preferences into decision-making.

Industry organisation

Institutional arrangements have not been addressed in this paper. In particular, farmers may share fixed costs in co-operatives and so offset the costs of provision of attributes that require large investments. Similar effects are likely for processing and retail firms that manage multiple establishments and so are able to share costs of certification, promotion and activities such as testing. Scale effects, in particular, are

more likely to be enjoyed by very large processors, and scope effects by retailers with a very large range of products and attributes on offer.

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DATA SOURCES

Table A.1. Data sources

Category	Comments	Source
Farm costs	Typical values drawn from farm cost studies.	Porskrog et al. (2003); Sparks (2003); Galletto (2003); Offermann and Nieberg (2002)
Processing costs	Generalized measures drawn from processing costs studies. Specific costs of attribute provision drawn from specialized studies.	Roche (2001); Sparks (2003); Erba et al. (1997); Maltsberger and Kalaitzandonakes (2000); ABARE (1994); Statistics Canada (2003); Ward (1993); Morrison Paul (2001)
Retail costs	Based on price differentials and a specialized study of attribute provision	Sparks (2003); Baker (2003); U.K. Competition Commission (2000)
Consumer price premia	Drawn from a variety of reports	Hobbs (2003); Offermann and Nieberg (2002); Galletto (2003)