2011

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DOI: https://doi.org/10.1002/9781118115800.ch17

HANDBOOK OF INTEGRATED RISK MANAGEMENT IN GLOBAL SUPPLY CHAINS

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A JOHN WILEY & SONS, INC., PUBLICATION

CHAPTER 1

PROCUREMENT RISK MANAGEMENT IN BEEF SUPPLY CHAINS

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1.1 INTRODUCTION

The purpose of the present paper is to develop a basis for understanding the tradeoffs facing a meat processing company (hereafter a "packer") in the choice of alternative arrangements for sourcing fed cattle, when that packer acts as a wholesaler into several final product markets. The general question posed is: what might influence a packer to source from long-term contracts versus spot markets as the basis for procurement of fed cattle when there are uncertainties and substitution possibilities in the demand for the resulting beef products supplied by the packer? Our focus is on the United States (U.S.) beef industry, which is the largest single industry within U.S. agriculture, generating between \$34 and \$37 billion per year in 2006-2008 and accounting for 20% of the annual total market value of agricultural products sold in the U.S. (USDA, 2009). A similar analysis would apply to other cattle producing regions of the world that rely for fed-cattle procurement on a mix of spot markets and long-term contracts (e.g. Europe and South America).

As shown in Figure 1.1, the beef industry is a combination of assembly and disassembly and of product flow smoothing. The base production unit in the industry - the beef cow herd - lives outdoors and consumes grass-based forage. The capital requirement in land is enormous and is the main reason why the cattle industry has not and will likely never integrate or consolidate. Beef cows produce a single calf per year and the large majority of calves are born in spring. Calves grow with the mother cow on grass pasture and are weaned in the fall. At this time the first major assembly occurs. Weaned calves are marketed through a multitude of auction barns and direct trade. Groups of calves are comingled and moved to so-called “backgrounding” operations. The purpose of backgrounding operations is to provide inexpensive animal growth on forage-based systems. Backgrounding operations include pasturing on growing winter wheat in the southern high plains, pasturing on stockpiled standing grasses, and feeding on inexpensive forages in confined operations. The length of backgrounding is highly variable, depending on the feeding regime. This variation in length of backgrounding is the primary means of smoothing the flow of cattle to packers.

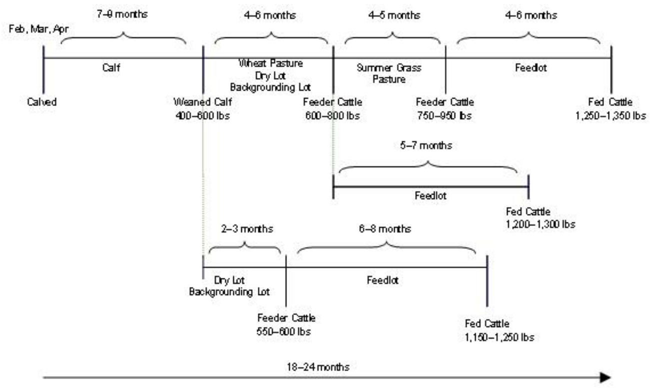

Figure 1.1 Typical Production System and Timeline in Beef Supply Chain (GIPSA Report, 2007)

The second major assembly occurs after backgrounding. After obtaining cheap growth of the animal frame, the animals are referred to as “feeder cattle” and are assembled by the cattle feeding industry. Feeder animals feed for 4-6 months depending on seasonal factors (such as energy requirements due to living outdoors and seasonal demand for beef consumption) and grain prices relative to beef prices. Finished animals are referred to as “fed cattle” and are marketed to packers.

As reported in the GIPSA Report (2007), there are some 25 large commercial fed cattle slaughtering and processing facilities in the U.S. And it is here that disassembly begins. Each animal can be used to produce a subset of hundreds of standard beef cuts. Further, excess fat is blended with lean beef trimmings - largely from the slaughter of non-fed beef animals which include cull beef cows and bulls - to produce a number of beef products. These are packaged as premium products (program boxed beef) or commodity products (commodity boxed beef). Finally, each animal is used to produce a subset of by-products. The largest by-product is the hide which is tanned for use as leather. The disassembly process continues through the beef distribution system. Food service such as restaurant chains may procure program beef. Grocery stores market a variety of commodity beef. There are distinct differences in regional demands across the U.S. and there is also a distinct variation in seasonal demands for types of beef products.

Beef markets have several interlinked markets that operate to determine pricing and delivery quantities at various stages along the supply chain. We will focus on the two markets of greatest interest to packers (see Figure 1.2):

1. The market between Processors/Packers and all upstream elements (including feedlots and prior elements) of the beef value chain;

2. The market between Processors/Packers and all downstream elements (including Wholesalers and Retailers) of the beef value chain.

Considering the upstream elements in the beef supply chain, there are actually two markets of interest: the spot market and the contract market.

Spot markets (also referred to as cash markets) are real-time regional markets for transactions of fed cattle, often through auctions. In keeping with the extensive literature on the subject, e.g. GIPSA Report (2007), we will assume throughout that spot markets are competitive, i.e. the price is not sensitive

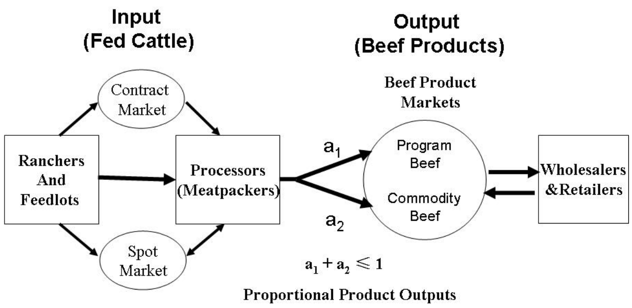

Figure 1.2 Upstream and Downstream Elements for Meatpackers in Beef Supply Chain

to the actions of any of the agents (Buyers or Sellers) who participate in this market.

Contract markets feature longer-term arrangements between feedlot owners and packers. The contracts themselves are often referred to as "marketing agreements". Such agreements may allow some flexibility in the quantity delivered, in the usual options form, or have more advanced features in pricing of yield risks (grid or formula-based) than fixed forwards based on, e.g., simpler live-weight metrics. The particular contract form analyzed below is the most common in the industry. It specifies the price per unit on the basis of the spot price prevailing at a specified market on delivery day. The usual form of this arrangement is that contract price equals spot price plus a fixed surcharge. The fixed surcharge is intended to cover the cost of additional feeding specifications that are part of the contract and, which give rise to the additional value of contract cattle resulting from the higher percentage of premium product (program beef) in these cattle. Contract cattle can also be resold in the spot market by the contracting packer, if they are not needed for production.

As noted in Kleindorfer and Wu (2003), in many organized commodity markets, a substantial portion of a Seller's output or Buyer's input is typically contracted for well in advance of delivery, with contract-based input in excess of 80% of total input, and where the spot market acts primarily as a topping up and hedge market. In contrast, for meatpackers in the U.S., the spot market is a very important source of physical supply, averaging for many meatpackers in excess of 60% of total supply according to GIPSA Report (2007), undertaken for the Grain, Inspection, Packers and Stockyard Administration (GIPSA) of the U.S. Department of Agriculture. This report provides the basic background and data for the computational experiments reported in this paper. The heavy reliance on the spot market noted in the GIPSA Report is driven in part by the large number of small producers of cattle, who raise cattle as complements to their other farming activities, and the fact that spot sales in organized markets are an efficient way of bringing such cattle to market. Contract purchases obtained from larger feedlots offer certain advantages to packers such as the ability to contract for and monitor special feeding regimes that are intended to increase the quality of meat produced.

For the upstream market between a given packer and its suppliers (see Figure 2), the appropriate model would be one in which, following Wu and Kleindorfer (2005), a uniform product is provided by multiple suppliers characterized by heterogeneous costs (with quality differences captured in these costs as adjustments to the "full price" of a standard product). As our focus is on the integration of upstream and downstream markets, we will treat the upstream contract market as a single aggregate supplier, ignoring the details of how equilibrium price in this contract market is determined. We also assume that neither the cattle nor the finished products can be inventoried–they have a certain "ripe" or sale date towards which all contracting is directed.

For the downstream market between Packers and Buyers (see Figure 2), model features that are important include: a multi-product model (each unit of upstream product yields a certain number of units of saleable downstream products); with some quality differences between contract and spot purchases. Plant utilization is a critical issue for packers as their production technology (and our model) exhibits strong economies of scale.

Focusing on a single packer, we consider the optimal mix of contract and spot purchases in providing input from upstream feedlots and spot markets. Once delivered or purchased, these cattle are processed immediately and converted into the two beef products of interest, a premium product (program beef) and a standard product (commodity beef). As in the co-production literature (e.g., Bitran and Gilbert, 1994), there is downward substitution in production in that all meat suitable for sale as premium product can be converted into the standard product. The downstream market into which the packer sells is price sensitive, and price is assumed to adjust to the quantity of both products sold into this market. As described in the GIPSA Report (2007), the market for beef products is competitive, so that the firm-specific price elasticity of demand for any given packer is large. At the market level, price adjusts quickly to clear all meat product and fed-cattle input markets. Further, meat product markets are closely related given the evident substitution effects between meat products. Imbalances in any individual market have impacts on other markets. Considerable volatility (both seasonal and product-based) exists in beef product and cattle markets and price-based clearance at the market level is critical.

In our companion paper, Boyabatlı et al. (2010), we develop the theoretical model and provide the optimal solution for the procurement portfolio of the packer.[1] The current paper describes the computational results for the above model based on data for the US beef industry described in the GIPSA Report (2007), and complemented by industry demand and supply studies. Our analysis is focused on determining the impact on the optimal procurement portfolio of spot price and demand uncertainty, the degree of substitution between products in final markets, as well as the cost characteristics of the packer and the nature of quality and cost differences in the contract and spot markets.[2] As the focus is on the short and medium term, capacity and processing technology are assumed fixed.

This paper intends to make the following contributions. It provides insights about integrated risk management of input and output risks for the central player in the beef supply chains, the packer. Using a calibration based on the GIPSA Report (2007), the paper provides a foundation for understanding the complementary roles of contract and spot markets. In particular, the paper elucidates for the first time the value of contracting in the beef supply chain. As reviewed in the next section, this has been a point of considerable controversy in the policy debate concerning the structure and operations of the

[1]The theoretical model developed in Boyabatlı et al. (2010) focuses on a more general contract form, a special case of which is the marketing agreement contract analyzed in this paper.
[2]A part of these computational results are also reported in Boyabatlı et al. (2010) some of which are further generalized with analytical proofs.

beef industry. In characterizing the structure of the optimal sourcing portfolio from a supply chain perspective, this paper provides an important contribution to the on-going debate on this issue. Beyond these contributions specific to the beef supply chain, our results also indicate the value of integrated risk management across marketing, sourcing and supply chain decisions.

The paper proceeds as follows. We review relevant literature in the next section. Thereafter follows our model description in §1.3. §1.4 provides numerical simulations to illustrate the comparative statics of model results for processing, product market and spot market parameters of interest. We conclude in §1.5 with a discussion of our managerial insights and the path forward for future research.

1.2 LITERATURE REVIEW

There is a rich literature in agricultural economics and operations management fields that considers supply chain contracting in the presence of spot markets. We refer the readers to Boyabatlı et al. (2010) for a review of the related literature from the operations management field. In this section, we will focus on the literature in the field of agricultural economics and management covering the beef industry. However, very little of this literature addresses supply chain management questions in a direct manner. This literature review will discuss some of the broader agricultural economic research, linking this to supply chain management questions addressed in the paper. There are three broad areas of relevant literature: demand analysis, supply modeling, and the efficiency of pricing methods for marketing agreements.

Concerning the demand side of the beef markets, estimation of demand[3] elasticities are critical for market and policy analysis. Demand is inelastic so small changes in quantities result in relatively large impact at the market level. There is considerable volatility in livestock and meat prices. Further, meat demand is intrinsically variable. Red meat demand expanded considerably with the expanding U.S. economy and incomes during the 1960s and 1970s. However, health concerns and a number of other factors contributed

[3]The industry standard for demand modeling is the Almost Ideal Demand System of Deaton and Muellbauer (1980). It is used in almost all the work referenced and has been found to produce elasticities with desirable forecasting properties (Kastens and Brester, 1996).

to sharp declines in red meat demand following 1980. This decline in demand continued until 1998 and placed considerable economic pressure on the red meats industries.[4] Improving red meat demand in the late 1990s has been well documented (e.g. Marsh, 2003). However, solid identification of the causes is not. The consumption of food away from home - or food prepared away from home - increases across the past years. Health related concerns appear to be less, specialized preparation appears to be better, improvements in meat processing and technology appear to be better, or some combination, and have resulted in increased red meat demand along with the increase in food not-prepared at home. The GIPSA Report (2007) suggests that marketing agreement transaction methods (the contract market in our model) have emerged to address meat quality problems that are not addressable through the federal government developed grades and standards. The findings of these studies above are used to synthesize reasonable elasticities for program versus commodity beef in the numerical simulations reported in this paper.

Concerning the supply side of beef markets, estimation of supply elasticities and the associated dynamic properties are critical for market and policy analysis. There are a large number of independent decision makers, the production process - the growth and development of beef animals - is lengthy, and the behavior by decision makers is in part anticipatory. A significant literature has examined the dynamic properties of supply functions at the various stages of cattle and beef production.[5]

Another important area of the supply-related literature addresses technical progress within the beef industry and increased productivity. For example, the additional pounds of beef produced per animal in the breeding herd have increased 25% over the past 20 years. There are also been large changes in meat processing technology, changes and reductions in organized labor, and changes in provision of marketing service. These effects are slower but have substantial impacts on markets over time. The increase in productivity has

[4] See, for example, Braschler (1983), Chavas (1983), Dahlgran (1987), Moschini and Meilke (1989), Verbeke and Ward (2001) and Boetel and Liu (2003).

[5] Initial supply modeling work includes Reutlinger (1966) and Nelson and Spreen (1974), and the later work by Marsh (1983, 1984, and 1994).

maintained the total volume of beef production with a significant reduction in the size of the breeding herd.[6]

A final extensive and important supply-related literature addresses long-term investment in the cattle industry and the resulting cattle cycle dynamics (e.g., Schmitz, 1997). There are inherent difficulties in modeling farm-level supply decisions and it may be that examining the herd building and liquidation decision itself is more useful. The cycle persists because there are cycle reinforcing actions and because expectations are still to a large part adaptive. The reinforcing actions are that when prices are relatively high and economic returns are favorable then returning additional young female animals to the herd and keeping additional cows in the herd exacerbates the high prices. Likewise, when prices are relatively low and economic returns are poor then selling young female animals into the meat production system and culling cows exacerbates the low prices. Further, expectation formation by beef producers have been found to be largely adaptive and not forward-looking (Antonoviz and Green, 1990). Generally, the study of the cattle cycle is important but has provided no simple rules as far as the predictability of the cycle.

On the efficiency of pricing methods in the beef markets, the pricing mechanisms for alternative marketing arrangements[7] such as marketing agreements have been a more resent research interest in the agricultural economics literature. All of this research is focused on determining welfare implications to suppliers based on the prospect of the exercise of market power by downstream procuring Buyers. Comprehensive supply chain management issues and the optimal contracting behavior of the meatpacker, the focus of this paper, have not been examined in detail in this literature.

Within producer groups, policy making and some government agency circles non-spot market procurement arrangements are referred to as captive supplies. These captive supplies are also referred to as contract supplies or marketing agreement cattle. These contracts are often more than simple forward contracts. Forward contracts comprise 5% of fed cattle transacted whereas the largest non-cash market arrangements are marketing agreements

[6]See, for example, Kuchler and McCelland (1989), Mullen et al. (1988), and Brester and Marsh (2001).

[7]The "alternative" refers to an alternative to the cash or spot market.

with formula pricing, in which the price paid for cattle is determined based on the amounts of each of type of beef actually present in the processed carcass. Large portions of participants within the beef industry have viewed such alternative marketing arrangements with skepticism and have often pushed for legislation to prohibit these arrangements. The most notable piece of legislation was the proposed Johnson Amendment to the 2000 Farm Bill. The amendment was not in the final bill, and a similar amendment was introduced but was not included in the 2008 Farm Bill, but there is persistent pressure by populist groups to limit or prohibit non-cash market transactions in the cattle industry[8]. We show in our paper that, from the meatpackers perspective, this pressure is misplaced in that alternative marketing agreement (a.k.a. contract) cattle are generally part of an efficient portfolio.

On the issue of competitive spot markets, Crespi and Sexton (2004) and Schroeder and Azzam (2003 and 2004) provide a detailed examination of a classic dataset collected by the USDA Grain Inspection and Packers and Stockyards Administration. These data were comprehensive information collected in the Texas Panhandle area where captive supplies are a substantial proportion of total volumes and where some of the political pressure is the greatest. Market power was found to be present, but its economic consequences are minor to negligible. Like early structure-conduct-performance research on industrial organization, difficulties in interpreting the empirical research has lead to theoretical studies of the problem. Azzam (1998) is one of the earliest studies and determines that the price impacts of captive supplies are ambiguous due to relative changes in supply and demand of spot market and non-spot market animals. Zhang and Sexton (2000 and 2001) examine the role of transportation costs as a source of market power. Xia and Sexton (2004) examine a theoretical model of top-of-the-market contract pricing clauses that are most often used with alternative marketing agreements. Wang and Jaenicke (2006) is the most recent research supported by

[8] There is a similar but weaker movement related to the use of non-cash market arrangements in the pork-hog industry where the volume of these arrangements is more than double that in the beef industry - based on the proportion of total industry volume accounted for by non-cash arrangements. Policymakers appear to treat the issue within the beef industry as unique to the beef industry and do not recognize that the practice of reliance on both contract and spot markets is persistent in almost all commodity industries, as discussed in Kleindorfer (2008).

results derived through simulation. The authors find that impacts of captive supplies on cash market price are ambiguous. While all of these studies find the potential for market power through the strategic use of non-cash market arrangements, few examine the potential efficiency benefits that may come with improved supply chain management, the focus of this paper. The exception is Love and Burton (1999) who build a model of captive supplies where the packing firm has declining average costs of processing with its processing facilities and an incentive to backward integrate to assure adequate supply to take advantage of its economies of scale.

Against the background of the above literature, we can note several important lacunae. For the upstream market, there is no research on the optimal mix of procurement methods (contract vs. spot) within the beef industry. Furthermore, the key issue of quality/yield risks (which are different across contract and spot procurement methods) needs to be addressed and integrated with production and demand management. For the downstream market, the key issue that needs to be addressed is that of multiple products arising from processed beef (premium and standard products) and the demand uncertainties and substitution effects associated with these. It is precisely on these key issues, and their related impacts on optimal processing decisions for the producer (here the meatpacker), that we focus our model and our results.

1.3 MODEL DESCRIPTION

This section describes our modeling framework that is developed in Boyabatlı et al. (2010). We consider a packer that procures and processes fed cattle to produce two beef-products, a premium (program beef) and a standard (commodity beef) product. We model the packer's procurement, processing and production decisions in a two-period framework. Before discussing the details of these decisions, we provide some notations that we will use throughout the paper. A realization of the random variable $\tilde{y}$ is denoted by y. $\mathbb{E}$ denotes the expectation operator, and bold face letters represent vectors of the required size. Vectors are column vectors and $'$ denotes the transpose operator. Monotonic relations are used in the weak sense unless otherwise stated. We use "C-cattle" to denote the cattle sourced from the contract market and "S-cattle" to denote the cattle sourced from the spot market.

1.3.1 Procurement Decision

In line with the above discussion, we consider two sources for procurement, marketing agreement contracts and spot markets. The marketing agreement contract specifies the number of C-cattle that are committed by the packer in advance of the spot market and are delivered to the packer on the spot day. The packer can also buy S-cattle from the spot market on the day. Let Q^C denote the number of C-cattle and $Q^S(P^S)$ denote the number of S-cattle at the prevailing spot price P^S. We assume that $\tilde{P}^S$ follows a normal distribution with mean μ_S and standard deviation σ_S.

There are differences between C- and S-cattle in terms of meat quality, processing cost and contract price. Processing C-cattle is cheaper and leads to a higher yield of carcass meat suitable for producing the premium product (where the additional yield is denoted as Δ). We will discuss these differences in detail later in this section. C-cattle are priced through formula (a.k.a. grid) pricing that tie the base price to publicly reported spot prices and specify surcharge for high quality meat (MacDonald, 2003). In line with this, in our model, the unit price of C-cattle is $P^S + v\Delta$ and is based on the prevailing spot price at the time of the delivery plus a surcharge ($v\Delta$) to reflect the higher quality of C-cattle. The unit price of S-cattle is the prevailing spot price P^S with an additive transaction cost $t > 0$ applied. This transaction cost reflects transportation cost from the auction barn (spot market) to the packers plant and weight loss between purchase and processing. The packer can also sell C-cattle which it receives under contract in the spot market. The unit sales price is $(1 - \omega)P^S$ where $0 < \omega < 1$ represents a transaction cost.

1.3.2 Processing Decision

Fed-cattle processing has two main characteristic features. First, packers have high incentives to increase plant utilization due to significant scale economies (Ward and Schroeder 2002). Second, animal non-uniformity creates frictions in cattle processing (Hennessy 2005); and C-cattle are more uniform than S-cattle (Hayenga et al. 2000). We define $\mathbf{z'} = (z^C, z^S)$ as the vector of processed cattle composed of C-cattle, z^C, and S-cattle, z^S. We assume that there exists a physical processing capacity constraint K (hereafter referred as plant size) such that $\mathbf{1'z} \leq K$; and the total processing cost is denoted by $C(\mathbf{z}) = c_0\mathbf{1'z} + \delta z^S + c_1(K - \mathbf{1'z})^2$. Here, c_0 is the common processing cost parameter, $\delta > 0$ represents the additional processing cost of S-cattle due to animal non-uniformity and c_1 is a (quadratic) utilization cost parameter. As the total processed cattle ($\mathbf{1'z}$) increases, the average unit cost $\frac{C(\mathbf{z})}{\mathbf{1'z}}$ decreases. In addition to the volume-variable costs, fixed costs are also important elements of the packer cost structure. They represent payments to capital providers and indirect facility costs. We neglect these in the model development as they do not affect the optimal solution. Fixed costs are reflected in the calibration underlying our numerical results in §1.4. Decreasing short-term average costs throughout the entire range of feasible input levels are well documented and important for packers in the beef industry (Koontz and Lawrence, 2010).

1.3.3 Production Decision

In the beef supply chain, beef products are grouped into two major categories, program beef and commodity beef. Program beef is the premium product. In our model, product 1 refers to program beef and product 2 refers to commodity beef. Each unit (head) of processed cattle leads to carcass capacities in fixed proportions that can be used for production.

We denote a_i^j as the fixed proportion of the carcass for product $i = \{1, 2\}$ from cattle type $j = \{C, S\}$. We assume $\mathbf{a_1'} = \left(a_1^C, a_1^S\right) < \mathbf{a_2'} = \left(a_2^C, a_2^S\right)$, i.e. carcass capacity is lower for the premium product than for the commodity product, whatever the source of the carcass. We also assume $a_1^j + a_2^j = s \leq 1$ for $j \in \{C, S\}$, i.e. the total carcass yield is identical for both cattle types and there could be yield losses in processing ($s < 1$). To capture the quality difference, we assume $a_1^C = a_1^S + \Delta$ and $a_2^C = a_2^S - \Delta$ where $\Delta \geq 0$ denotes the quality difference of C-cattle. C-cattle have a higher carcass capacity for the premium product. Since the total carcass capacity is fixed, the proportion of the standard product is higher with S-cattle.

The firm-specific demand for beef products is stochastic, price-dependent and represented by the linear inverse-demand functions $p_1(\mathbf{x}, \xi_1) = \xi_1 - b_1x_{11} - e(x_{22} + x_{12})$ and $p_2(\mathbf{x}, \xi_2) = \xi_2 - b_2(x_{22} + x_{12}) - ex_{11}$. Here, $\mathbf{x}' = (x_{11}, x_{22}, x_{12})$ is the production vector, e represents the cross-price elasticity parameter and ξ_i, b_i, p_i denote the market size, own price slope of the demand function and price for product i respectively. In the production vector $\mathbf{x}$, x_{kl} denotes the quantity of product l produced from the meat capacity ($\mathbf{a_k'z} = a_k^C z^C + a_k^S z^S$) dedicated to product k. We assume that $\boldsymbol{\xi'} = (\xi_1, \xi_2)$ follows a bivariate normal distribution with mean vector $\bar{\boldsymbol{\xi}}' = (\mu_1, \mu_2)$ and covariance matrix $\boldsymbol{\Sigma}$, where $\boldsymbol{\Sigma}_{ii} = \sigma_\xi^2$ and $\boldsymbol{\Sigma}_{ij} = \rho_\xi \sigma_\xi^2$ for $i \neq j$ and ρ_ξ denotes the correlation coefficient. Since the first product is premium product, we have $\mu_1 > \mu_2$, i.e. for identical quantities, the expected price of the first product is higher; and $b_1 > b_2$, i.e. the first product demand is less responsive to changes in price than the second product. In particular, we assume $b_2 < b_1 \frac{a_1^S}{a_2^S}$. This is an appropriate assumption for beef markets where price sensitivity is considerably higher for premium products than for standard products.

We allow for two different substitution channels for production. There exists *demand substitution* through the cross-price elasticity parameter e. Since beef-products are natural substitutes, the price of each product is decreasing in the price of the other product ($e > 0$) and this cross-price effect is lower than the own-price effect ($e < \min(b_1, b_2)$). There is also *downward product substitution*: the packer can produce standard product using the carcass capacity dedicated to premium product, and not vice versa. We assume that the packer uses a market clearing pricing strategy, i.e. all the available carcass is processed into one of other of the two beef products and price is adjusted in profit-maximizing fashion to sell all finished products.

1.3.4 The Model

We model the packer's decision problem as a two-stage stochastic recourse problem. In stage 0, the packer decides on the number of C-cattle (Q^C) to contract with respect to spot price $\tilde{P}^S$ and product market $\tilde{\boldsymbol{\xi}}$ uncertainties. At stage 1, these uncertainties are realized and Q^C is delivered to the packer. The packer decides on the number of cattle to buy from the spot market (Q^S), the number of cattle to process out of the available S-cattle (z^S) and C-cattle (z^C), the number of cattle to sell back to the spot market ($Q^C + Q^S - z^C - z^S$) and the production quantities of two beef products that either come from their dedicated carcass capacities (x_{11}, x_{22}), or through substitution of the premium product carcass capacity to produce standard product (x_{12}). The objective of the packer is to maximize the expected total profit at stage 0.

We now formulate the packer's decision problem starting from stage 1:

$$\begin{aligned}
\max_{Q^S,\mathbf{z},\mathbf{x}} \quad & -Q^C(P^S+v\Delta) - Q^S(P^S+t) + (1-\omega)\,P^S\left[Q^C+Q^S-\mathbf{1}'\mathbf{z}\right] \\
& -\left[c_0\mathbf{1}'\mathbf{z}+\delta z^S+c_1(K-\mathbf{1}'\mathbf{z})^2\right] \\
& +x_{11}\left(\tilde{\xi}_1-b_1x_{11}\right)+(x_{22}+x_{12})\left(\tilde{\xi}_2-b_2\,(x_{22}+x_{12})\right)-2e\,(x_{22}+x_{12})\,x_{11} \\
\text{s.t.} \quad & z^C \le Q^C, \quad z^S \le Q^S, \quad \mathbf{1}'\mathbf{z}\le K \\
& x_{11}+x_{12}=\mathbf{a_1'z}, \quad x_{22}=\mathbf{a_2'z} \\
& Q^S\ge 0, \quad \mathbf{z}\ge\mathbf{0}, \quad \mathbf{x}\ge\mathbf{0}.
\end{aligned} \tag{1.1}$$

In (1.1), the first two terms represent the total procurement cost of the packer. The third term is the revenue from spot market sales and the fourth term is the total processing cost of the packer. The final terms in the objective function denote the sales revenue from the beef products. The first two constraints ensure that the packer does not process more than the available capacity of a particular cattle type. The third constraint guarantees that the packer processes within plant size. The fourth and the fifth constraints represent the available carcass capacity for each beef product under market clearing pricing strategy. Let $\Pi(Q^C;P^S,\boldsymbol{\xi})$ denote the optimal stage 1 profit for a given Q^C.

Anticipating these decisions, at stage 0, the packer solves for the optimal number of C-cattle to contract, Q^{C^*}, to maximize the expected firm profit: $V^* = \max_{Q^C\ge 0}\mathbb{E}\left[\Pi(Q^C;\tilde{P}^S,\tilde{\boldsymbol{\xi}})\right]$ where the expectation is taken over $\tilde{P}^S$ and $\tilde{\boldsymbol{\xi}}$. We assume that the distributions of these two random variables are statistically independent. To deal with the non-negativity of the market price, we assume that the coefficient of variations are not extremely large, and hence, the effect of negative values is negligible.

We refer the reader to Boyabatlı et al. (2010) for the explicit characterization of the optimal contracting decision. We close this section with an important observation about the efficiency of contract market in the beef supply chain. As reported in Hayenga et al. (2000), packers note the following factors driving contract-market procurement: i) risk of not being able to obtain cattle from the spot market, ii) non-uniformity of S-cattle and corresponding higher processing costs, and iii) higher quality of C-cattle over S-cattle. In parallel with this empirical observation, in our model, it is straightforward to show that if there is no spot procurement transaction cost ($t = 0$), no additional processing cost for S-cattle ($\delta = 0$) and no quality difference between C-cattle and S-cattle ($\Delta = 0$), then the packer does not contract any C-cattle. In the next section, we shed more light on the the main drivers of the optimal procurement portfolio as well as on several performance measures using numerical experiments.

1.4 COMPUTATIONAL EXPERIMENTS FOR THE BEEF SUPPLY CHAIN

This section describes computational results for the above model. Our primary objective is to provide insights on some fundamental intuitions about the optimal integration of upstream contracting and downstream demand management. This section is calibrated on the typical packer, in terms of size and cost characteristics, described in the GIPSA Report (2007), thus allowing further insights into some of the controversies surrounding that important study. The GIPSA data on packer characteristics were complemented by industry demand and supply studies. The GIPSA data pertain to the U.S. beef industry for the period October 2002 through March 2005. We focus on an average sized plant (see Tables 3.2, 3.3 and Figure 3.1 of the GIPSA Report) with rated capacity of 25,000 head of cattle per week (corresponding to the mean plant size of the GIPSA Report of 103,733 cattle per month as reported in Table 3.2). Tables 1.1, 1.2 and 1.3 provide the benchmark values for this packer and the relevant range for the sensitivity analysis.

Spot and Contract Market Characteristics			
Notation	Description	Benchmark Value	Range
ω	Transaction cost in spot sales (percentage)	4% of P^S	0% to 4% of $\tilde{P}^S$ with 0.5% increments
t	Transaction cost in spot procurement	4% of μ_S ($64/head)	
μ_S	Mean Spot Price	$1600/head	
σ_S	Spot Price Volatility	8% of μ_S (128)	4% to 9% of μ_S with 1% increments
v	Surcharge parameter for quality difference of C-cattle	($4800/head) Δv=3.75% of μ_S	2.5% to 4.25% of μ_S for surcharge ($v\Delta$) with 0.25% increments

Table 1.1 Description of the spot and contract market characteristics in numerical studies.

The mean spot price μ_S is set to be $1600 (per head) and is in line with the average auction barn (spot market) price of $1.32 per pound (with an average

Processing Characteristics			
Notation	Description	Benchmark Value	Range
c_1	Utilization cost parameter	\$0.001	0, 0.001, 0.003, 0.005, 0.01, 0.015, 0.025, 0.05, 0.1
c_0	Common processing cost parameter	\$100/head	0 to 250 with 50 increments
δ	Non-uniformity cost of S-cattle	\$1.39/head	0 to 2.78 with 0.695 increments
K	Plant Size	25000 head/week	

Table 1.2 Description of the processing characteristics in numerical studies.

Product Market Characteristics			
Notation	Description	Benchmark Value	Range
e	Cross-price elasticity parameter	0.005	0 to 0.01 with 0.0025 increments
b_1	Own price coefficient for program beef	0.035	
b_2	Own price coefficient for commodity beef	0.01	
μ_1	Mean demand of program beef	3800	
μ_2	Mean demand of commodity beef	3000	
$\sigma_{\xi_1} = \sigma_{\xi_2} = \sigma_\xi$	Demand variability	6% of μ_2 (180)	3% to 8% of μ_2 with 1% increments
ρ_ξ	Demand correlation	0.9	0.75 to 1 with 0.05 increments
a_1^S	Fixed proportion of program beef with S-cattle processing	0.18	
a_2^S	Fixed proportion of commodity beef with S-cattle processing	0.42	
Δ	Quality Difference $= a_1^C - a_1^S = a_2^S - a_2^C$	0.0125	0 to 0.015 with 0.0025 increments
s	Total proportion of usable carcass $= a_1^C + a_2^C = a_1^S + a_2^S$	0.60	

Table 1.3 Description of the product market characteristics in numerical studies.

weight of 1200 lbs per head) as reported in Table 5.1 . We set σ_S, spot price variability to 8% of μ_S and is consistent with the reported variability of average weekly prices in Table 5.1. The surcharge paid for the quality difference of C-cattle, $v\Delta$, is set such that the average procurement price of C-cattle and S-cattle are identical as follows from Table 5.1 (the average price of C- and S-cattle are reported as \$1.32 per pound).

The GIPSA data on packer characteristics were complemented by industry demand and supply studies. For example, t, transaction cost in spot procurement, is set to be 4% of the mean spot price μ_S. This 4% represents the pencil shrink on the cattle purchased from the spot market. The shrink is the water loss in the animal between the feedlot and packing plant. Since C-cattle tend to be produced close to the plant, and the shrink is far less than the market driven 4% and is reasonably close to (and set to be) zero.

On the cost calibration, we focus on 25000 head cattle processing, 50% of which comes from the spot market (as consistent with the GIPSA Report). We calculated average total cost (ATC), that is total processing cost divided by the total quantity processed, at 95%, 75% and 50% utilization rates. The benchmark ATC number (at 95% utilization) is \$139 and is taken from Table 3.1 of the GIPSA Report. The cost estimation in the GIPSA Report illustrates that a plant operating at 75% utilization rate has an ATC that is 6% higher than the benchmark ATC; and a plant operating at 50% utilization rate has an ATC that is 14% higher than the benchmark ATC. Moreover, the increase in ATC is more significant at lower utilization rates. The non-uniformity cost δ corresponds to the 1% of the benchmark ATC. Finally, fixed facility costs of $900K$ per week were assumed, representing fixed staffing and maintenance costs and payments to investors, which is representative of the range of fixed costs of medium-sized U.S. plants. To determine the final calibration, we minimized the sum of the quadratic difference between the estimated and the specified target ATC values at 95%, 75% and 50% utilization rates. The resulting cost parameters (fixed cost, δ, c_0 and c_1) provide a good fit to the observed pattern above.

On the demand calibration, since the beef product demands are highly correlated, we set ρ_ξ to be 0.9. Since demand variability is lower than the spot price variability, as consistently observed in the beef markets, we set σ_ξ to be 6% of the mean demand of the standard product (μ_2). The demand parameters, own price coefficients b_1 and b_2, and cross-price elasticity parameter e, are set to be sufficiently low such that the firm-specific price elasticity of demand is large. With the resulting set of parameters, the expected beef price (calculated from expected price of each product rated by its corresponding fixed proportion) is calculated as \$2.60 per pound. This is consistent with the average beef price reported in Table 1.4 of the GIPSA Report (The reported gross price is \$2.62 and the net price is \$2.57). The expected profit of the packer is calculated as \$2.04 million per week, and corresponds to 5.6% of the total sales revenues from two beef markets. These two profit measures are representative features of a medium-size packer in the beef industry.

As final validation tests of the model calibration, we analyze the optimal sourcing portfolio, expected utilization and the expected spot selling of the C-cattle. As depicted in Figure 1.3, in the period of the GIPSA study (October 2002 to March 2005), the ratio of spot procurement is higher than, yet close to, the contract procurement. At the benchmark parameter values, the optimal sourcing portfolio is composed of 41.6% contract market procurement and 58.4% spot market procurement. This is consistent with the observed pattern in Figure 1.3.

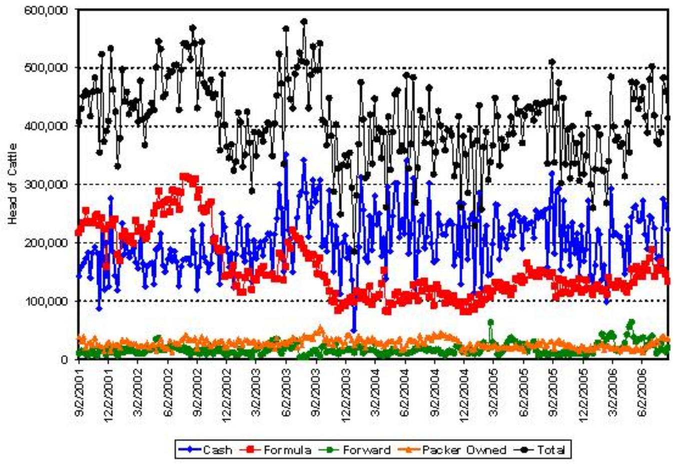

Figure 1.3 Sourcing Classification of Fed cattle Procurement in Beef Supply Chains: Here, “cash” refers to spot market procurement; and “formula” refers to the marketing agreement contracts.

The expected utilization of the packer is calculated to be 77% and the expected spot sales ratio (the ratio of expected spot number of C-cattle sold back to the spot market to the total C-cattle) is 2.2%, i.e. the packer almost always uses C-cattle for processing. These two numbers are also consistent with the characteristics of a medium-size packer in the beef industry.

For computational experiments, we programmed the first-order-condition and the other performance measures in MATLAB. We validated the code against a number of tests that included making comparisons between the MATLAB results and i) explicitly calculated optimal values for the performance measures when $\tilde{\boldsymbol{\xi}}$ and $\tilde{P}^S$ equaled their mean values (in this case, σ_ξ and σ_S were assigned very low values so that all the probability mass was located at the mean); ii) results of several special cases of the problem for which we analytically know the behavior of the optimal performance measures (for example, for $\omega = v = 0$ we have $Q^{C^*} = K$), and iii) a number of comparative static results that can be proven analytically (for example, Q^{C^*} is decreasing in ω).

A number of performance measures were computed for the experiments reported here, all of them evaluated at the optimal solution to the packer's expected profit maximization problem. Specifically, we report:

PERF-1. *The optimal volume of C-cattle to contract:* Q^{C^*}

PERF-2. *Expected spot procurement at the optimal solution:* $\mathbb{E}[Q^{S^*}]$

PERF-3. *Optimal portfolio (contract intensity) ratio:* $\frac{Q^{C^*}}{Q^{C^*}+\mathbb{E}[Q^{S^*}]}$

PERF-4. *Expected optimal profit of the packer:* $\mathbb{E}[\Pi^*]$: This includes \$900,000 in fixed costs (including payments to owners/investors) per week.

PERF-5. *Value of contract market:* $\frac{\mathbb{E}[\Pi^*(Q^{C^*})]-\mathbb{E}[\Pi^*(0)]}{\mathbb{E}[\Pi^*(Q^{C^*})]}$. This captures the relative value loss between the packer using the optimal number of contracts and the packer not using any contracts.

PERF-6. *Value of spot market:* $\frac{\mathbb{E}[\Pi^*(Q^{C^*})]-\mathbb{E}[\Pi^*(Q^{C^*}|t\to\infty,\omega\to 1)]}{\mathbb{E}[\Pi^*(Q^{C^*})]}$. This captures the relative value loss between the packer using the optimal number of contracts (with spot involvement) and the packer using the optimal number of contracts (without spot involvement).

PERF-7. *Expected capacity utilization of the packer's plant:* $\frac{\mathbb{E}[z^*]}{K}$ where z^* denotes the optimal processing volume at stage 1.

To illustrate the impact of the various parameters of interest from Tables 1.1, 1.2 and 1.3, we first compute the elasticity of the performance measure with respect to each of the parameters, for a variation of $\pm 5\%$ around the benchmark case. Elasticity of performance metric "F" w.r.t. parameter"p" is defined as $\frac{\partial F}{\partial p} \times \frac{p}{F}$, and therefore represents the percentage change in F arising from a one percentage point change in p. The results of this exercise are shown in Table 1.4. Second, we numerically analyze the impact of these parameters over their entire range as specified in Tables 1.1, 1.2 and 1.3. The arrows in the cells in Table 1.4 indicate these results. Some of these results are non-monotonic. In these cases, we demonstrate the impact with multiple arrows in the order of observation as the parameter of interest increases. For example, ↓↑ implies that the particular performance metric first decreases then increases with an increase in the parameter of interest.

	Contract PERF-1	Spot PERF-2	Portfolio PERF-3	Profit PERF-4	C- Value PERF-5	S- Value PERF-6	Utilization PERF-7
c_0	-1.13804 ↓	0.419687 ↑↓	-0.90230 ↓	-0.59950 ↓	-1.41721 ↓	2.11155 ↑	-0.25744 ↓
e	-0.19233 ↓	0.035710 ↑	-0.13331 ↓	-0.10353 ↓	-0.14660 ↓	0.48714 ↑	-0.05842 ↓
δ	0.10003 ↑	-0.062454 ↓	0.09516 ↑	-0.00507 ↓	0.26556 ↑	-0.02956 ↓	0.00336 ↑
Δ	-3.72820 ↓	3.086226 ↑	-3.52313 ↓	-0.13318 ↓	-6.58813 ↓	2.35207 ↑	-0.26155 ↑↓
ω	-0.48103 ↓	0.148112 ↑	-0.46067 ↓	-0.00347 ↓	-0.80789 ↓	-0.01457 ↓	-0.00913 ↑
v	-6.69295 ↓	3.439525 ↑	-6.56454 ↓	-0.08706 ↓	-8.83006 ↓	2.23974 ↓	-0.31326 ↑
c_1	0.42442 ↑	-0.194364 ↓	0.36397 ↑	-0.02799 ↓	0.97425 ↑	-0.16225 ↓↑	0.05766 ↑
σ_S	-2.07179 ↓	0.614115 ↑	-1.93687 ↓	0.19425 ↑	-3.86640 ↓	0.84328 ↑	-0.15958 ↓
σ_ξ	-0.99127 ↓	0.545250 ↑	-0.87836 ↓	0.13939 ↑	-2.04259 ↓	0.84293 ↑	-0.12723 ↓
ρ_ξ	-0.20042 ↓	0.103052 ↑	-0.17646 ↓	0.02742 ↑	-0.43698 ↓	0.16120 ↑	-0.02517 ↓

Table 1.4 Impact of Parameters on The Performance Measures

As an example, consider the impact of Δ on Q^{C^*} in Table 1.4. The elasticity of Q^{C^*} w.r.t. Δ is given as -3.72820. Noting the linear approximation being used here to estimate elasticities, this means that, in the neighborhood of the Base Case, an increase in Δ of 1% would lead to a 3.72820% decrease in Q^{C^*}, *ceteris paribus*. This monotonic behavior is also observed over the entire range of Δ as depicted by ↓. An increase in Δ has two effects: first, it increases the fraction of premium product in C-cattle with positive profit impacts given the higher price for the premium product; second, it increases the surcharge paid over the spot price for C-cattle (with the surcharge equal to $v\Delta$). Given the value of v in the market, the second effect dominates the first in our numerical experiments.

As can be seen further in Table 1.4, an increase in Δ would lead to an increase in spot procurement, a decrease in the contract intensity ratio, a decrease in expected profits, a decrease in the value of the contract market and an increase in the value of the spot market. The impact on the expected capacity utilization is non-monotonic. When Δ (thus, the surcharge) is sufficiently low, the firm contracts up to the plant size. In this case, expected processing quantity $\mathbb{E}[z^*]$ increases in Δ as higher price for the premium product induces the packer to process more of C-cattle (and sell less of it to the spot). Therefore, expected utilization increases. When Δ is sufficiently high, the firm does not contract up to plant size. In this case, a higher Δ decreases Q^{C^*} and expected utilization decreases.

Rather than dwell on the rationale and intuition for each of the results shown in Table 1.4, we focus on the effects of input and output price variability, contract market transaction costs, quality difference between C- and S-cattle, utilization cost parameter, and product and demand substitution.

1.4.1 Effect of Spot Price and Product Market Variability

In this section, we analyze the effect of spot price variability (σ_S) and product market variability (σ_ξ, ρ_ξ) on the key performance indicators. For brevity, on the impact of product market variability, we will only provide figures for σ_ξ.

As depicted in Panel A of Figure 1.4, Q^{C^*} decreases in σ_S. In our numerical experiments, we observe that the packer almost never sells C-cattle back to the spot market. Therefore, the impact of the spot price variability on the optimal contract volume is through its impact on the spot procurement. Since the packer only buys from spot market when spot price is sufficiently low, with a higher σ_S, the packer benefits from low spot price realizations by procuring S-cattle cheaper, whereas the packer is not affected from the high spot price realizations. Therefore, the packer's reliance on S-cattle increases, and in turn, Q^{C^*} decreases.

For the effect of σ_ξ and ρ_ξ on Q^{C^*}, we note here that a higher σ_ξ or ρ_ξ increases the variability of product market returns. For ρ_ξ, this is because a higher correlation decreases the diversification benefit from operating in two markets. Since C-cattle is always processed (and is not sold back to the spot market), the change in the variability of product market returns does not have an impact on the expected marginal value of processing the C-cattle. On the other hand, the packer processes S-cattle (after all the C-cattle is processed)

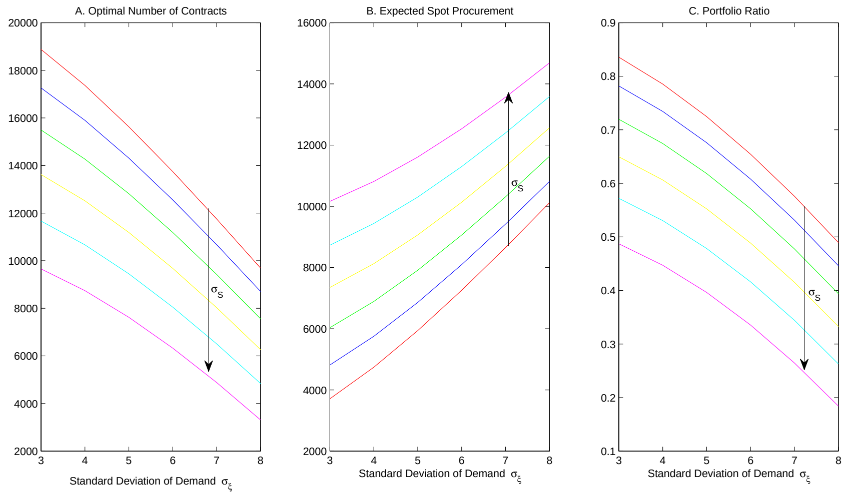

Figure 1.4 Impact of Spot Price Variability (σ_S) and Product Market Variability (σ_ξ) on the Optimal Procurement Portfolio: σ_S ranges from 4% to 9% of the mean spot price (μ_S) with 1% increments and σ_ξ ranges from 3% to 8% of the mean demand of the standard product (μ_2) with 1% increments.

only if the product market return is sufficiently high. In other words, with a higher σ_ξ or ρ_ξ, the S-cattle processing benefits from the higher variability in product market returns. Since the packer relies more on the S-cattle, Q^{C*} decreases. The result with respect to σ_ξ is depicted in Panel A of Figure 1.4.

We now analyze the effect of variability on the expected spot procurement. As depicted in Panel B of Figure 1.4, with a higher σ_S or σ_ξ, expected spot procurement increases. The same holds true with an increase in ρ_ξ. These results are driven by two effects: First, S-cattle processing benefits from a higher σ_S (a higher σ_ξ or ρ_ξ). This is because the packer optimally processes S-cattle only when the spot price is sufficiently low (or the product market return is sufficiently high). Second, Q^{C*} decreases and the packer relies more on the spot procurement. As Q^{C*} decreases and the expected spot procurement increases, the optimal portfolio ratio decreases in σ_S and σ_ξ as depicted in Panel C of Figure 1.4. The same holds true with an increase in ρ_ξ.

For the impact on the expected profit, we first analyze the effect of σ_S. The packer has two options on the spot market: spot selling and spot procurement.

As we pointed out above, expected spot selling is very small in the optimal solution within our numerical setting. Since the packer optimally procures from the spot market only if the spot price is sufficiently low, the value of spot procurement increases in σ_S. Therefore, the expected firm profit increases in σ_S as depicted in Panel A of Figure 1.5. The effect of σ_ξ and ρ_ξ on the expected firm profit is driven by the value of the processing option of the firm. Since the firm optimally processes only when product market return is sufficiently high, a higher variability of product market return, i.e. a higher σ_ξ or ρ_ξ, increases the value of processing option of the packer, and thus, the expected optimal profit. The result with respect to σ_ξ is depicted in Panel A of Figure 1.5.

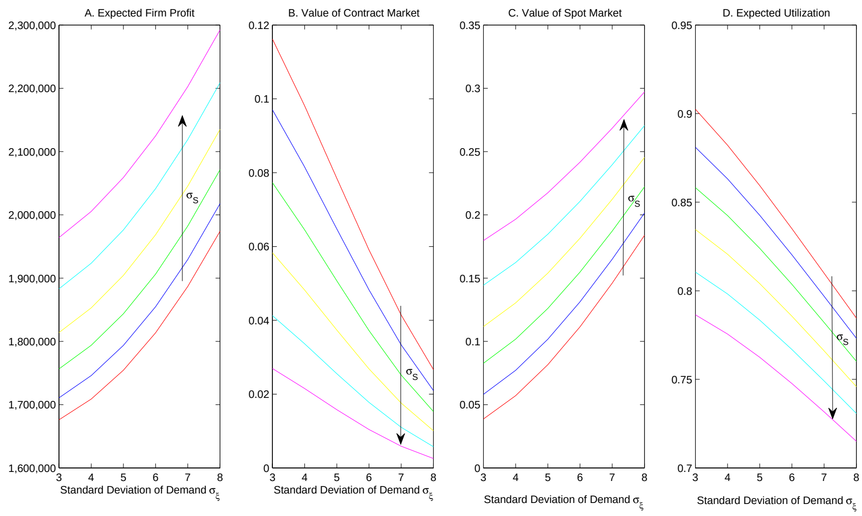

Figure 1.5 Impact of Spot Price Variability (σ_S) and Product Market Variability (σ_ξ) on the Expected Firm Profit, Value of Contract and Spot Market and Expected Utilization: σ_S ranges from 4% to 9% of the mean spot price (μ_S) with 1% increments and σ_ξ ranges from 3% to 8% of the mean demand of the standard product (μ_2) with 1% increments.

With an increase in σ_S or σ_ξ, a lower (higher) dependence on contract (spot) market leads to a lower (higher) value of contract (spot) market as depicted in Panel B (C) of Figure 1.5. The reduction in the volume of C-cattle processing dominates the increase in the volume of S-cattle processing and the expected total number of input processed decreases. As a result, expected utilization decreases (Panel D). These results continue to hold with an increase in ρ_ξ.

1.4.2 Effect of Contract Market Transaction Costs (v and ω)

In this section, we analyze the effect of the transaction cost for spot sales (ω) and the value surcharge for the quality difference of C-cattle (v) on the key performance indicators. As ω increases, the value of spot resale of the C-cattle decreases. As v increases, the contract procurement cost increases. Therefore, as depicted in Panel A of Figure 1.6 below, with an increase in ω or v, the optimal contract volume decreases. In turn, the expected spot procurement increases (Panel B) and the optimal portfolio ratio decreases (Panel C).

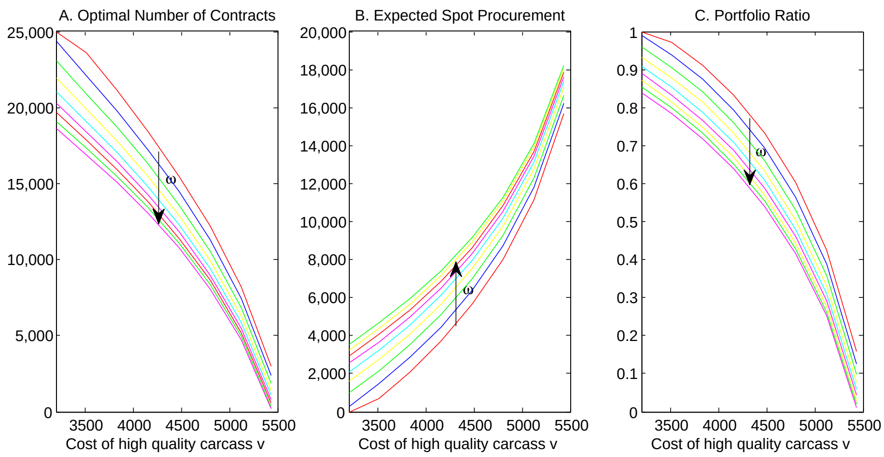

Figure 1.6 Impact of Transaction Cost in Spot Sales (ω) and Surcharge for High Quality Carcass (v) on the Optimal Procurement Portfolio: ω ranges from 0% to 4% with 0.5% increments and v ranges from 3200 to 5440 with 320 increments (or equivalently, the quality premium $v\Delta$ ranges from 2.5% to 4.25% of the mean spot price μ_S with 0.25% increments).

The increase in the contract procurement cost (with an increase in v) and the decrease in the profitability of spot resale (with an increase in ω) decreases the expected firm profit as depicted in Panel A of Figure 1.7. With an increase in v or ω, a lower (higher) dependence on the contract (spot) market leads to a lower (higher) value of the contract (spot) market as observed in Panel

B (Panel C). The decrease in the volume of C-cattle processing outweighs the increase in the volume of S-cattle processing and the expected utilization decreases (Panel D).

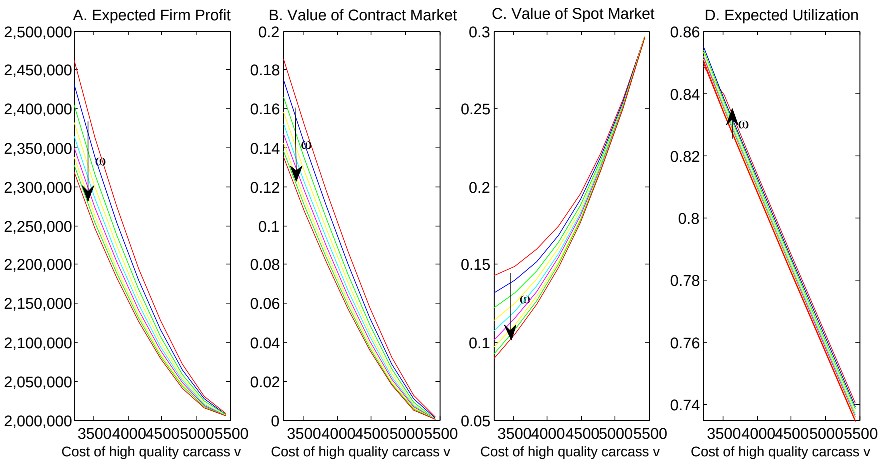

Figure 1.7 Impact of Transaction Cost in Spot Sales (ω) and Surcharge for High Quality Carcass (v) on the Expected Firm Profit, Value of Contract and Spot Market and Expected Utilization: ω ranges from 0% to 4% with 0.5% increments and v ranges from 3200 to 5440 with 320 increments (or equivalently, the quality premium $v\Delta$ ranges from 2.5% to 4.25% of the mean spot price μ_S with 0.25% increments).

1.4.3 Effect of Quality Difference between C-cattle and S-cattle (Δ)

As Δ increases, there are two opposite effects, the cost effect and the revenue effect. On the cost side, the contract procurement cost increases as the additional surcharge is tied to Δ. On the revenue side, the premium (standard) product yield from C-cattle increases (decreases). Consistent with the practice, in our numerical experiments, we observe that the premium product market is more profitable than the standard product market. Therefore, a higher Δ increases the value of C-cattle processing.

As depicted in Panel A of Figure 1.8, with an increase in Δ, the cost effect dominates the revenue effect and Q^{C^*} decreases. For a given Q^C, expected spot procurement is independent of Δ. Since Q^{C^*} decreases, the expected spot procurement increases (Panel B) and the optimal portfolio ratio decreases

(Panel C). It is interesting to note that even when there is no quality difference ($\Delta = 0$), the packer optimally contracts up to full capacity K. Despite the early commitment requirement of contract procurement, additional non-uniformity processing cost δ and transaction cost t of S-cattle together with the low level spot resale transaction cost ω induce the packer to prefer C-cattle over S-cattle.

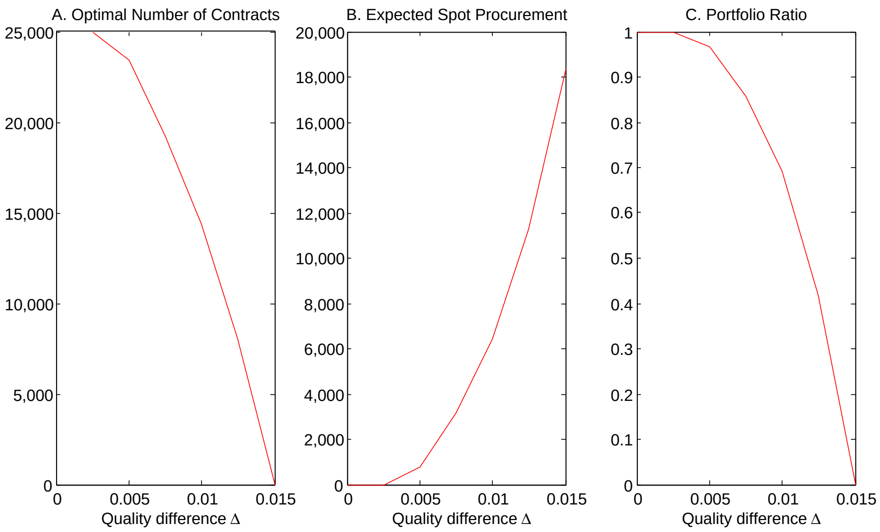

Figure 1.8 Impact of Quality Difference (Δ) on the Optimal Procurement Portfolio: Δ ranges from 0 to 0.015 with 0.0025 increments.

For the effect on the expected profit, the cost effect dominates the revenue effect and the expected profit decreases with an increase in Δ as depicted in Panel A of Figure 1.9. A lower (higher) dependence on the contract (spot) market leads to a lower (higher) value of the contract (spot) market (Panel B). The expected utilization first increases then decreases as shown in Panel C. For significantly low levels of Δ, the packer optimally contracts up to the full plant capacity and there is no spot procurement. In this case, an increase in Δ increases the value of C-cattle processing and a lower volume of C-cattle is sold to the spot market. Therefore, the expected utilization increases. For higher levels of Δ, the packer contracts less than the plant capacity and relies on the spot procurement. In this case, with an increase in Δ, the decrease in the volume of C-cattle processing outweighs the increase in the volume of S-cattle processing and the expected utilization decreases.

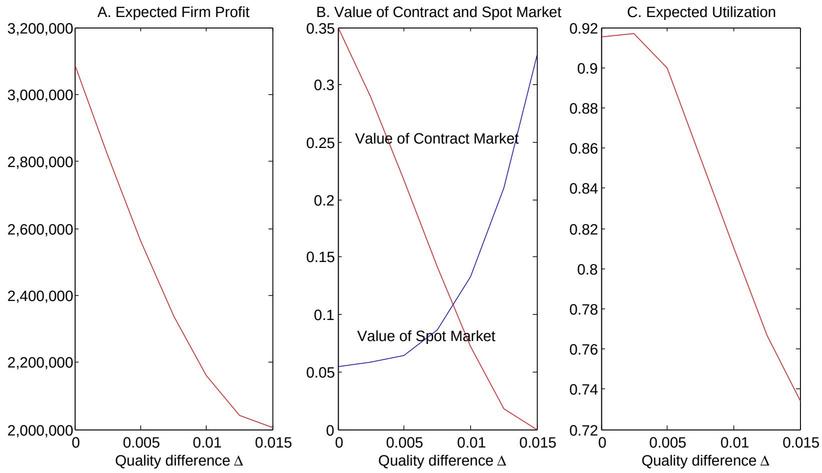

Figure 1.9 Impact of Quality Difference (Δ) on the Expected Firm Profit, Value of Contract and Spot Market and Expected Utilization: Δ ranges from 0 to 0.015 with 0.0025 increments.

1.4.4 Effect of Utilization Cost Parameter c_1

As depicted in Panel A of Figure 1.10, a higher c_1 increases the optimal volume of C-cattle: As the cost of underutilization of the plant capacity K increases, the packer contracts more to lessen the impact of underutilization. In other words, the contract market provides a hedge against increasing utilization penalty cost. Although for a given Q^C the expected spot procurement would increase for the same reason, a higher Q^{C*} decreases the expected spot procurement. Therefore, the optimal portfolio ratio increases (Panel C).

A higher c_1 decreases the expected profit as depicted in Panel A of Figure 1.11. Since the firm relies more (less) on the contract (spot) market with an increase in c_1, the value of the contract (spot) market increases (decreases) as shown in Panel B (Panel C). Since the packer almost never sells back the C-cattle to the spot market, and uses C-cattle for processing; with an increase in c_1, the increase in the volume of processed C-cattle outweighs the decrease in the volume of S-cattle and the expected utilization increases as depicted in Panel D.

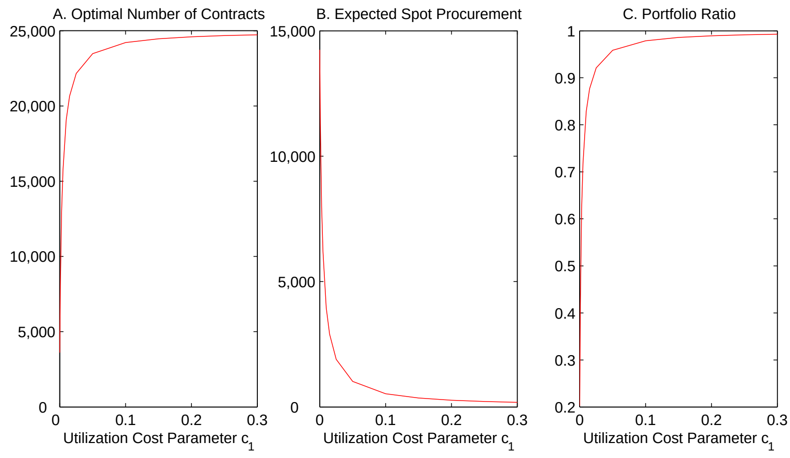

Figure 1.10 Impact of Utilization Cost Parameter (c_1) on the Optimal Procurement Portfolio: c_1 range is in the set of $\{0, 0.001, 0.003, 0.005, 0.01, 0.015, 0.025, 0.05, 0.1\}$.

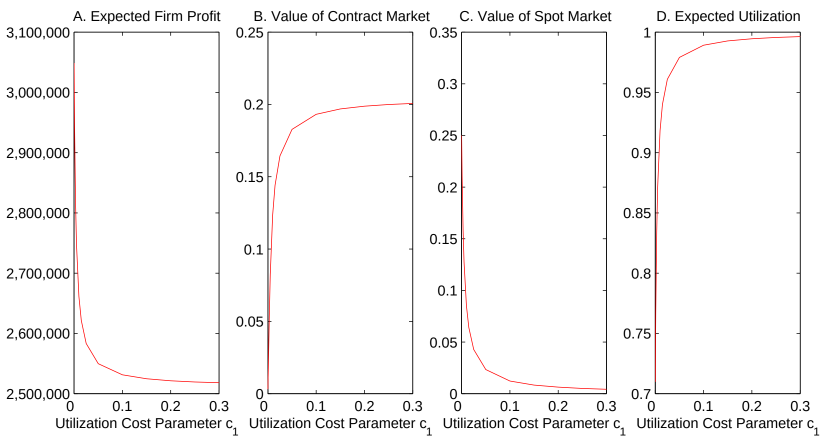

Figure 1.11 Impact of Utilization Cost Parameter (c_1) on the Optimal Procurement Portfolio and Expected Firm Profit: c_1 range is in the set of $\{0, 0.001, 0.003, 0.005, 0.01, 0.015, 0.025, 0.05, 0.1\}$.

1.4.5 Effect of Demand and Product Substitution

The effect of *demand substitution* (through the cross-price elasticity parameter e) is driven by the change in the product market profitability, and hence the value of processing. As e increases, since the two outputs are substitutes, for fixed production levels, the price of each product decreases. This leads to a lower product market profitability as the firm is not able to price differentiate between the two markets due to the higher cross-price effect. Therefore, higher demand substitution decreases the value of processing. It follows that Q^{C*} decreases with an increase in e, as depicted in Panel A of Figure 1.12 below. Although for a given Q^C, the expected spot procurement decreases in e due to lower value of processing, the reduction in Q^{C*} leads to an increase in the expected spot procurement (Panel B). Therefore the optimal portfolio ratio decreases (Panel C).

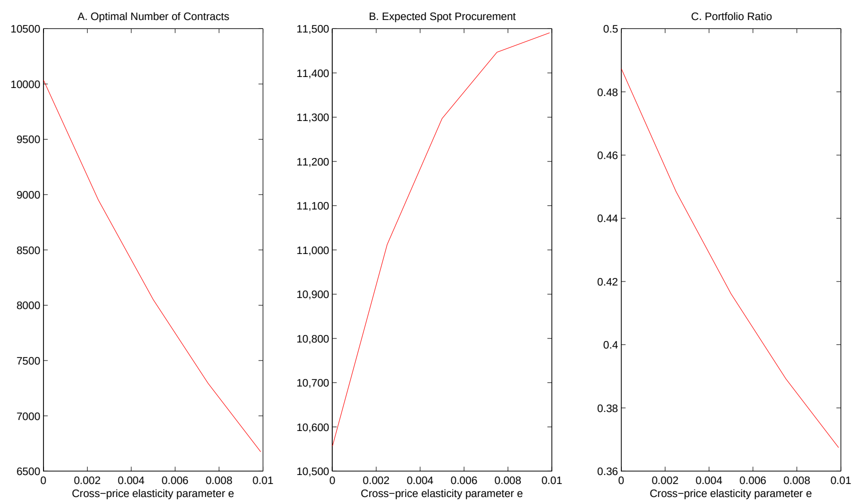

Figure 1.12 Impact of Demand Substitution (through cross-price elasticity parameter e) on the Optimal Procurement Portfolio: e ranges from 0 to 0.01 with 0.0025 increments.

As depicted in Panel A of Figure 1.13 below, with an increase in the cross-price elasticity parameter e, a lower value of processing decreases the expected firm profit. A lower (higher) dependence on the contract (spot) procurement leads to a lower (higher) value of the contract (spot) market as depicted in Panel B. The decrease in the volume of C-cattle processing outweighs the increase in the volume of S-cattle processing and the expected utilization decreases (Panel C).

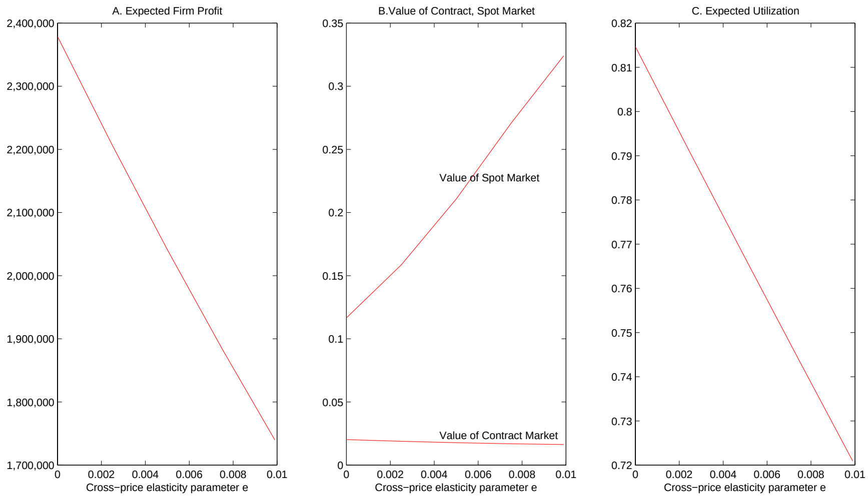

Figure 1.13 Impact of Demand Substitution (through cross-price elasticity parameter e) on Expected Firm Profit, Value of Contract and Spot Market and Expected Utilization: e ranges from 0 to 0.01 with 0.0025 increments.

The effect of *product substitution* is driven by the product substitution regime used by the firm. To understand the extent of product substitution, we explicitly calculate the expected premium product substitution ratio $\frac{\mathbb{E}[x_{12}^*]}{\mathbb{E}[x_{11}^*+x_{12}^*]}$ in our numerical experiments. However, product substitution does not have any value for the calibration implied by the GIPSA data; for this data the firm optimally does not use any product substitution. This observation is consistent with empirical observations, as packers rarely convert premium product (program beef) to standard product (commodity beef) in practice.

We note here that the ineffectiveness of product substitution partly depends on the high value of product market correlation ρ_ξ. The optimal substitution regime is determined by the difference between two market prospects. As demand correlation decreases, the asymmetry between the two markets increases, and the firm starts using partial and full product substitution regimes. As depicted in Figure 1.14 below, the expected premium product substitution ratio increases with a decrease in ρ_ξ for sufficiently negative correlation levels. In this case, product substitution does have a significant effect on the key performance measures.

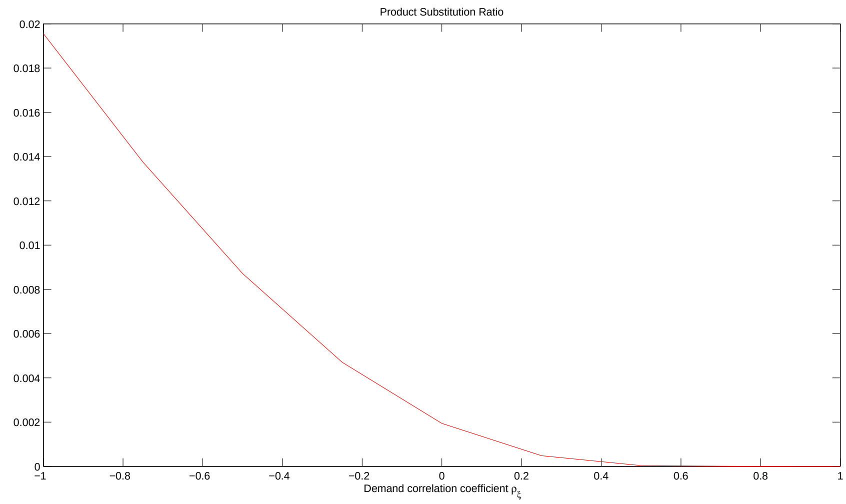

Figure 1.14 Impact of Demand Correlation (ρ_ξ) on the Optimal Expected Product 1 Substitution Ratio $\left(\frac{\mathbb{E}[x_{12}^*]}{\mathbb{E}[x_{11}^*+x_{12}^*]}\right)$: ρ_ξ ranges from -1 to 1 with 0.25 increments.

1.5 DISCUSSION

Our results provide insights on several open questions of importance to the beef industry, including the efficiency and value of contract markets, which has been a fundamental bone of contention in the beef industry for decades. Among others, we have the following managerial insights. Lower variability in the input and output markets increases the value of the contract market relative to the spot market. Thus, the packer should increase the contract procurement with a decrease in variability. Interestingly, the packer does not benefit from lower variability. This is because the packer makes money out of the uncertainties in the market place (both spot and product market). Since the firm optimally responds to such uncertainties, lower variability in the markets decreases expected profits (in the usual spirit of real options). A higher quality difference between fed cattle sourced from contract and spot market does not necessarily benefit the packer, as this difference is reflected in the surcharge premium of the contract price. When the packer faces an increase in the utilization penalty costs, the contract market should be used more extensively to secure processing volume to hedge against the increasing processing costs.

It is important to bear in mind that the calibration for the numerical studies reported was undertaken at mean values of the parameters reported for the period October 2002 to March 2005. For this base case, the value of the contract market was not high (see Table 1.4). However, there were significant periods during the time frame of the GIPSA study in which the input and output market parameters dictated a much higher value of contract markets, as our sensitivity analysis indicated (e.g., the impact of σ_S and σ_ξ). Indeed, central to understanding the value of the contract market for packers is the variability in market parameters across time and the relative fixedness of packer technology and cost structures. The flexibility accorded by increased sourcing alternatives, including the contract market, is therefore extremely important in responding to market fluctuations over the life of the packer's plant.

The usual caveats apply in interpreting the results of a single set of parameters. Even with this caveat in mind, what is apparent in the present context is the richness of the interactions across various drivers of the key performance indicators. One of the most important elements of the beef context is the fact that, as is typical in fed-cattle markets, contract prices and spot prices are closely linked through the standard contract. Even with this close link, the sensitivity of the optimal portfolio to variability in both upstream and downstream markets is significant (e.g., see Table 1.4). What this indicates is a strong interaction among upstream and downstream factors. This is all the more evident when considering the impact on optimal contracts, profits and utilization from the other factors characterizing these markets. For example, changes in quality determinants of the contract (captured in Δ) can have significant impacts on the optimal portfolio. Of course, the main drivers of the optimal portfolio are the mean values of prices of contract and spot cattle, and the price sensitivity and variability in the final product markets. All of these vary considerably over time depending on supply and demand of the respective cattle entering into these two markets (e.g., See Figure 2.1 and the ensuing discussion in the GIPSA Report (2007), which describes very significant changes over time in prices in the U.S. beef industry during the period 2002-2005 of that study). As a result, what one can expect is that the optimal portfolio, and the value of the contract market itself, will change over time, and at times dramatically, as determinants of supply-demand and prices change. This is consistent with the basic story of this paper and other contributions to supply management under risk: namely, there is real value in the integration of risk management, production and marketing, and all the more so under conditions of varying environmental conditions and fixed plant size and technology.

There are a number of limitations to the present study. The model analyzed reflects the specific characteristics of the U.S. beef market, which has a number of idiosyncrasies, including the pricing of contract procurement relative to the spot market. In other contexts, the price in the contract purchases could well be fixed and/or subject to other determining factors (e.g., the competitive model developed in Wu and Kleindorfer (2005)). Moreover, even for other live animal supply chains, such as pork-hog and broiler-chicken, there are important differences from the beef market (e.g., for the pork-hog market, one would see a higher proportion of the premium product, i.e. $a_1 > a_2$, in contrast to the beef supply chain, and the optimal operating regime would be different with important consequences for different substitution results). These comments and noted limitations suggest a number of open research questions.

There are several empirical avenues that are opened by the results of this study. These include both comparisons of different size plants, and of the performance and structure of sourcing portfolios as market conditions vary. In addition to these matters of direct interest to both industry and policy makers, there are also other interesting features in the model presented that deserve empirical study. These include the effect of contracting terms (such as options and resale value parameters), utilization and scale effects (which are reported to be extremely important in packer decisions), and the impact of price level and volatility on spot and contract cattle purchasing decisions. These are all very interesting for the beef industry. In addition, other effects modeled here, such as product and demand substitution, may be even more important in other markets.

Concerning risk management, our focus has been on physical procurement only. Extensions to overlay the cash flows from this physical problem with financial hedging are an important area of future research. In the beef industry, for example, there are significant variations over time in market conditions and operating profits of meat packers. To the extent that profit smoothing would avoid financial transactions costs under such variable market conditions, financial hedging can be of significant value. Financial options defined on either input or output markets can serve this purpose. As noted in Kleindorfer (2008), these hedge markets need not be identical with the sourcing markets as long as they are sufficiently highly correlated with these markets.

In addition to short-term issues, there are also important capacity investment and technology choice issues in the longer term. Intuitively, it is clear that the tradeoffs involved between scale economies, operational flexibility (in downward substitution and yields) are likely to be richer and more complex in a fixed proportions technology world than in a single-input, single-output world. From the numerical analysis in this paper, we already see that these tradeoffs will involve complex interactions between the magnitude of the scale economies and the entire fabric of the short-term optimization problem (solved here for the beef market) given capacities. A deeper examination of these with an appropriate temporal separation between capacity/technology choices and shorter term operating and contracting choices would be interesting.

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