EVALUATION OF ALTERNATIVE COORDINATION SYSTEMS BETWEEN PRODUCERS AND PACKERS IN THE PORK VALUE CHAIN

by

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Executive Summary

The traditional organization of the hog production/slaughter and processing system, characterized by independent producers and open market coordination with packers, is being challenged as never before. To combat the product and information flow mismatches, and other difficulties associated with the use of spot markets, producers and packers have been using contract and vertical integration mechanisms to secure product flows and improve information flows between the producer and packer. Vertical integration and coordination may occur for several reasons including stable supplies, better quality control, improved flow scheduling, and reductions in price risk (Paarlberg et al.).

Few empirical or numerical analyses of these changes, drivers, and impacts have been conducted. In particular, the impacts of different coordination mechanisms on the information, product, and financial flows in the hog production-packing system have not been quantified. This research seeks to quantify impacts associated with different coordination mechanisms. Using a system's approach, this research accounts for changes over time reflected in input and output prices and changing demands. The research reported here is an empirical quantification of the contributions of various coordination arrangements, or governance structures, to improvements in overall producer-packer system performance. The specific objectives are the study are:

1. To estimate pork producer-packer sub-sector performance under different forms of market coordination in a stochastic framework. Performance measures include assessments of financial and economic outcomes by analyzing the costs, revenues, and margins for producers, packers, and the sector as a whole. The specific forms of market coordination to be analyzed include:
    a. Traditional spot markets,
    b. Marketing contracts, and
    c. Vertical integration arrangements.
2. To determine the accuracy of price premium/discount schedules for yield and grade in the traditional open market system of coordination compared to specific quantity and quality orders in contract and vertical integration systems, and assess the implications of more accurate information on the incentive for producer-packer coordination.

These results of this analysis suggest the following conclusions:

1. The choice of coordination mechanism doesn't alter total system performance dramatically as measured by margins and their volatility, but the coordination mechanisms differ in how they distribute the risks and returns to producers and the packer.
2. Spot markets and contracting had the same variability associated with producer margins, as the marketing contract arrangements modeled were intended to only provide market access and not reduce risks.
3. Marketing contracts did not offer packers any margin risk reduction over spot markets, but they did increase the pounds of usable pork per hog delivered and reduced the variability of the pounds of usable pork per hog delivered compared to the spot market.

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Chapter 1: Introduction

Significant structural change has taken place in the agricultural sector over the last twenty years. The traditional organization of the hog production/slaughter and processing system, characterized by independent producers and open market coordination with packers, is being challenged as never before. Consumers are demanding a greater diversity of products with very specific characteristics that challenge the ability of a traditional system to respond. Flow and quality controls necessary to satisfy consumers' desires, suggest a possible role for closer coordination from genetics through processing and retailing than has been achieved in the past. Lawrence, et al. note, "The U.S. pork industry is rapidly evolving from one of relatively small independent producers and processors connected by the spot markets to a contract-coordinated industry involving fewer and substantially larger firms." As the hog industry evolves to a more industrialized style, the mechanisms used to coordinate product flows and pricing have also changed. The use of production and marketing contracts, weight/leanness premium and discount (P&D) pricing schedules, and packer owned and operated hog production facilities are now pervasive in the sourcing and pricing of hogs.

Traditional spot markets have long linked producers who are looking to maximize their returns from growing hogs with packers who are looking to maximize their returns from slaughter, processing, and the sale of primal cuts. In theory, the innovation of a P&D schedule "signals" to producers the hog weight and leanness characteristics that are valued in the marketplace. In fact, Hayenga et al. (1995) point out that carcass merit P&D schedules may have contributed to improvements in pork carcass leanness. Among other information, the production sector uses the P&D information and expected price levels in future periods to optimally plan hog flows. But the actual hog flows, in terms of carcass volume, may differ from what packers' desire. This mismatching is attributable to producers and packers having differing objectives. The lack of information in a coordination mechanism can result in misalignment for the production of output-specific characteristics in the short-run (Cloutier). When the product flow does not coincide with the information flow from the P&D schedules, the system's profit may be sub-optimal, providing an opportunity to increase overall system profits by realigning product and information flows.

Limited information in a system can restrict the system's ability to create value over time. Mechanisms that align the objectives of production and packing sectors are able to improve the transfer of information and provide Pareto improvements from status quo for both parties (Cloutier). This can be difficult when producers are optimizing their objectives with information they have available, and packers are using different information sets to make their optimal decisions. The common ground in both the producer and packer's decision is live hog prices and pork product flows. Producers want to receive a high price and have an assured market for their hogs, while packers want to pay a low price for live hogs while maintaining a steady flow of live hogs into their plant. This can create physical and economic mismatches between producers and packers. Furthermore, mismatches occur when P&D schedules reward for specific weight and leanness categories, but the biological and economic constraints will not allow producers to deliver animals in those categories.

To combat the product and information flow mismatches, and other difficulties associated with the use of spot markets, producers and packers have been using contract and vertical integration mechanisms to secure product flows and improve information flows between the producer and packer. The uncertainty and search costs of finding markets are motivating producers and packers to increase their use of contracts and vertical integration mechanisms. These coordination mechanisms also benefit producers and packers by improving the product quality and reducing overall transaction costs associated with marketing and purchasing of live hogs (UDSA 1996b). Processors have increased their use of non-market coordination mechanisms to improve the accuracy and timing of product and information signals.

Vertical integration and coordination may occur for several reasons including stable supplies, better quality control, improved flow scheduling, and reductions in price risk (Paarlberg et al.). In the past twenty years, the fraction of hog production coordinated by non-spot market coordination mechanisms has grown to over 80 percent. Exchange relationships between producers and meatpackers are changing, with less reliance on spot markets and more reliance on longer-term contractual relationships (MacDonald and Ollinger). And within the last seven years, the fraction of hog production by packer owned facilities or through vertically integrated mechanisms has grown to almost 25 percent of total production.

Problem Statement

Numerous analysts have described the structural changes occurring in the production-packing sub-sector, the changing nature of the information flows, the linkages between the stages in the pork supply chain, the potential drivers of (or reasons for) these changes, and the potential impact of the changes on consumers, producers, processors and systems performance (Need References)[1]. But few empirical or numerical analyses of these changes, drivers, and impacts have been conducted. In particular, the impacts of different coordination mechanisms on the information, product, and financial flows in the hog production-packing system have not been quantified. This research will assist business decision-makers and policy analysts by providing detailed information on the impacts associated with different coordination mechanisms. Using a system's approach will enable the measurement of these impacts to account for changes over time reflected in input and output prices and changing demands. The research reported here is an

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[1] Previous Studies have focused on describing the structural changes in the live hog production sector (Hayenga; Grimes and Rhoades; Rhoades and Grimes; Lawrence, et al;); the drivers or forces resulting in those structural changes (Barry, Sonka and Lajili; Sporleder; Rhodes; Reimund, Martin, and Moore; Hobbs and Frank; Henderson; Boehlje, et al; Kleibenstein and Lawrence; Brewer, et al; USDA 1996a; USDA 1996b; Srivastava, Ziggers, and Schrader; Hennessy and Lawrence); describing the structural changes in hog slaughter and process (MacDonald, et al;); the drivers or forces resulting in those structural changes (Hayenga, et al (1985); Hayenga, et al (1988); Barry, Sonka and Lajili; Srivastava, Ziggers, and Schrader; Johnson and Foster; Barkema, Drabenstott, and Welch; Barkema and Cook; Boehlje et al; Perry, Banker and Green; USDA 1996b; MacDonald and Ollinger; Melton and Huffman; Önal, Unnevehr, and Bekric); the forces underlying vertical integration, coordination and contracting (Azzam and Parrlberg; Haley; Pritchett; Boehlje, et al; Drabenstott; Cloutier and Sonka; MacDonald and Ollinger; Sporleder; Lawrence, et al; Perry, Banker and Green; USDA 2000; USDA 1996b; Kliebenstein and Lawrence; Grimes and Meyer); and the implications of concentration and coordination on spot market performance (Perry, et al; Paarlberg, et al; USDA 1996a; Paarlberg, Haley, and Pritchett; Martin: Lawrence, Grimes and Hayenga; Perry, Banker and Green).

empirical quantification of the contributions of various coordination arrangements, or governance structures, to improvements in overall producer-packer system performance.

Objectives

This research empirically estimates the impacts of using coordination mechanisms including spot markets, contracting, and vertical integration on producers and packers. The focus is on the improvements to profitability and benefits of information sharing associated with these mechanisms.

The specific objectives of this research are:

3. To estimate pork producer-packer sub-sector performance under different forms of market coordination in a stochastic framework. Performance measures include assessments of financial and economic outcomes by analyzing the costs, revenues, and margins for producers, packers, and the sector as a whole. The specific forms of market coordination to be analyzed include:
   a. Traditional spot markets,
   b. Marketing contracts, and
   c. Vertical integration arrangements.

4. To determine the accuracy of price premium/discount schedules for yield and grade in the traditional open market system of coordination compared to specific quantity and quality orders in contract and vertical integration systems, and assess the implications of more accurate information on the incentive for producer-packer coordination.

The analysis focuses on the benefits of information sharing and improvements in profitability associated with alternative coordination mechanisms that more tightly align live hog production with slaughter and processing. The goal is to determine: 1) differences that arise from the use of spot markets, contracts, and vertical integration coordination mechanisms in terms of information and product flows, and 2) measurable incentives from using coordination mechanisms other than spot markets including providing packers with a more consistent and higher quality live hog flow, and increased producer and packer margins and less uncertainty associated with total system margins relative to the spot market system.

Chapter 2: Model Overview

The focus of this research is the interface between hog production and slaughter and processing in the pork sector value chain (Figure 1). Three models of hog producer-packer systems are used to evaluate the effects associated with increased vertical coordination. Specifically, the models analyze the impacts resulting from improved price and product flow information. The information transfers and interactions in each system will be governed by one of three coordination mechanisms. The coordination mechanisms used are spot markets, contracts, and vertical integration. Each system model has four components: feeder pig placements, biological growth, hog marketing/primal sales, and input-output markets. The system models focus on the accuracy of information flows from the packer to the producer and the resulting physical flow schedules for live pork, and returns for producers, packers, and the system as a whole.

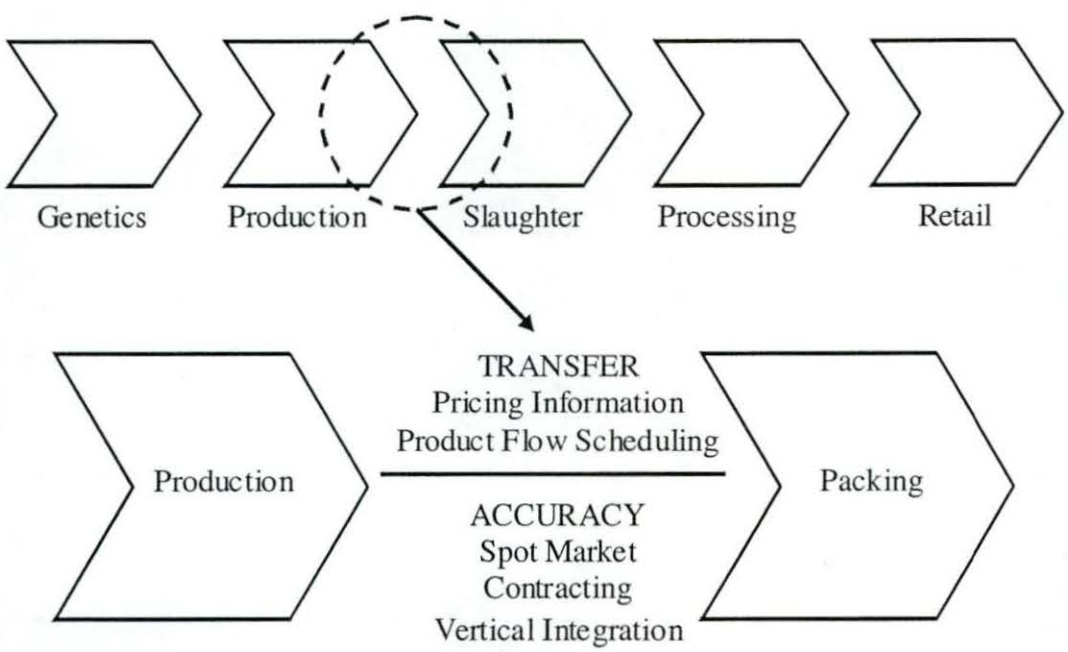

Figure 1. Producer-Packer Interface in the Pork Industry Value Chain

The models used to address the coordination issues discussed earlier are stochastic sequential mathematical programming models of optimal producer and packer decision-making in the pork production and packing system. The models build on previous research that has focused on similar but different aspects of production and packing. Producers and packers are assumed to maximize returns over variable costs (Shah, Okos, and Reklaitis). Producers activities consist of finishing feeder pigs and marketing finished hogs. Packers' activities include procuring live hogs, determining P&D schedules, and storing and selling primal pork cuts. The input and output markets for producers and packers incorporate dynamic market effects (McCarl and Spreen; Onal et. al.; and Spreen, McCarl, and White). Unlike the price endogenous models that model systems at the sector level, this research focuses on an individual packer and a group of producers in a close geographic region. Market dynamics are modeled using multivariate time series models, where price endogenous models solve for input and output prices given sector supply and demand. The results from the methodology used in this research are similar to the price endogenous model, where both producers and the packer are price takers in their respective input and output markets.

Three dynamic system models of hog production and packing are developed to measure the impacts associated with three different coordination mechanisms through simulation of the system on a weekly basis over a two-year period. The three system models are differentiated based on the coordination mechanisms used between production and packing. The three coordination mechanisms analyzed are spot market coordination (SM), contract coordination (CC), and vertically integrated coordination (VI).

Spot market transactions are defined as sales between producers and packers where the only transfer of information is a premium and discount grid for weight and leanness characteristics. Neither the production nor the packing sub-sector has any influence on the base price paid for live hogs and the packer buys all pigs marketed by the producers. Contract market transactions are sales of live hogs from the production sub-sector to the packing sub-sector by means of pre-arranged sales contracts. The contracts are "shackle space" agreements that assure producers of a place to market live hogs. The producers own the hogs while they are in the finishers and transfer ownership with their sale. The contract design is such that producers are paid a fixed payment per hog delivered in addition to the market price for live hogs plus (less) any premiums (discounts) for weight and leanness characteristics. The premium and discount schedule is identical to the spot market. In the contract system the packer has a call option for delivery on the live hogs and guarantees that all hogs will be marketed within a fixed period of time. In the vertical integration system, the packer owns the live hogs throughout and thus makes the sole determination as to when they are transferred from production to packing.

Model Components

There are five main components to the system models (Figure 2). The components are: feeder pig placement, biological growth, live hog marketing, primal cut sales/storage from packer operations, and input/output market prices. Figure 2 illustrates an overview of the model and outlines the pigs flows. The model begins with the placement of feeder pigs determined by a stochastic process. The feeder pig placement stochastic process is modeled using state-space time series techniques. Separate feeder pig placement models were used for each of the system models reflecting the alternative coordination mechanism structures. Feeder pigs mature into market weight hogs according to biological growth equations similar to those used by Craig and Schinckel and have two unique characteristics, weight and leanness. These growth equations were estimated with data from feeding trials and a non-linear mixed effects model was used for estimation to better quantify the variation in animal growth between each pig and between groups of pigs.

The third component of the system models is a live hog marketing model. In the spot market system producers determine optimal live hog flows to the packer based on maximizing returns over variable costs from finishing feeder pigs. The producer will make these marketing decisions based on an expectation of market prices in the future. These expectations are modeled using time series forecasting techniques where the producer only has information based on

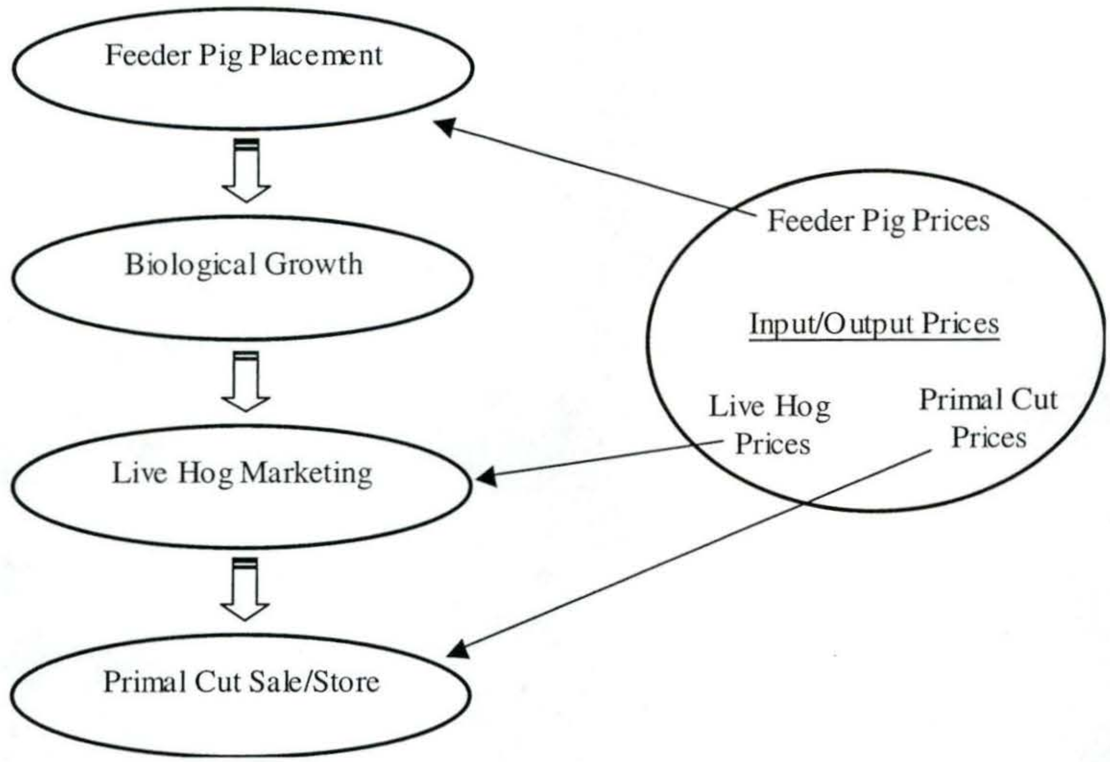

Figure 2. Graphical Overview of the System Model

current and historic live hog prices, current hog inventories, and packer provided premium and discount schedules. In the contract system model the packer determines optimal hog flow from maximizing returns over variable costs from processing live hogs into primal cuts. The packer determines optimal hog flow based on expectations of primal cut values and live hog procurement costs. The Packer's expectations are formed based on times series modeling techniques where the packer has information on current and past live hog and primal cut prices as well as current inventory levels of live hogs and primal cuts. This larger information set may allow the packer to make more accurate flow scheduling decisions than the producer could make given the producer's limited information set. Finally, the vertical integration system model does not market live hogs, rather the packer transfer hogs from their finishing unit to their slaughter and processing unit based on maximizing returns over variable costs from processing feeder pigs into primal cuts. In this case, the packer makes optimal decisions based on expected primal cut prices and the costs of feeding pigs. The time series model used to form expectations in this case does not contain live hog prices since they are irrelevant.

The fourth component to the system models is the packer's primal cut sale/storage decision model -- the packer produces six primal cuts: hams, bellies, loins, picnics, ribs and butts. In all system models the packer determines optimal primal cut sales/storage from maximizing their returns over variable costs from slaughter and processing given a predetermined live hog supply.

The fifth and final component is an input and output market price model. This model uses time-series modeling techniques to forecast industry wide prices and quantities over the two-year simulation period. The market prices for live hogs and primal cuts are used in the system models, where appropriate. All system models face the same price for all inputs and outputs, except in the case of live hogs for the vertical integration system where live hog prices are irrelevant.

Model Component Simulation

The feeder pig placement and biological growth model are simulated on a weekly basis over a period of two years for 100 stochastic iterations to determine inputs to the live hog marketing model. The live hog marketing and primal cut sales/storage models are then solved sequentially given the simulated inputs. The outputs from these models are optimal marketings of live hogs and optimal sales of primal cuts. The packer's behavior is specified by each coordination mechanism and prohibits them from exhibiting any form of non-competitive behavior. Additionally, the use of the state-space input and output market price models further restricts both producers and the packer from exploiting market power.

The stochastic sequential optimization problem in these models was simulated for one hundred iterations of 176 weeks (three years and twenty weeks). The twenty-week period allows for feeder pig growth from the initial batch's placement in the first period ($t = 1$), and the three years are used to simulate the effects of the different coordination mechanisms. The first year of simulated data provides historical data that is used to calculate P&D schedules in year two. The system models were solved and simulated using the General Algebraic Modeling System (GAMS) software. A more technical description of the modeling methodology can be found in Appendix A.

Chapter 3: Results

The methodology described above attempts to model much of the information flow that exists between producers and packers. This information flow, as suggested by previous research, may lead to different physical and financial flow (See, Chapter 2 page 6). To evaluate the performance of each system model two main groups of outputs will be analyzed. First, the physical flows of each system will be examined to see if differences exist in the quantity and quality of the live hogs delivered to the packer. Physical flows refer to the feeder pigs placed in finisher barns, quantity of hogs delivered to the packer, and the corresponding pounds of lean pork associated with those live hogs. Second the financial flows of each system will be analyzed. Financial flows include producer, packer, and system margins. The performance measures evaluated include simulation averages, standard deviations, coefficient of variation, and minimum and maximum values as well as graphical illustrations of risks and returns in the form of cumulative density functions and probability density functions.

Physical Flows

Physical Flow Performance of Alternative Coordination Systems

Physical flow measurements include feeder pig placement, number (head) of hogs delivered to the packer, and pounds of lean pork delivered to the packer. Pounds of lean pork delivered are the total pounds of primal cuts produced from each hog, which measures the types of live hogs each system is delivering to the packer. Table 1 summarizes the physical flow results from the system models. Each of the system models average feeder pig placements and

Table 1. Summary Model Results – Physical Flows (Averages Over 100 Two Year Iterations, negative values in parentheses)

	Coordination Mechanism		
	Spot Market	*Contract $5/Head Bailment*	*Vertical Integration $20/Head Flat Fee*
Feeder Pig Placement			
Average	73,410	74,250	74,183
Std Dev	4,831	5,259	4,927
CV	6.58%	7.08%	6.64%
Min -- Max	40,866 -- 101,818	41,602 -- 109,978	37,838 -- 107,378
Head Delivered			
Average	73,394	74,155	74,144
Std Dev	6,964	5,402	4,841
CV	9.49%	7.29%	6.53%
Min -- Max	41,085 -- 98,745	42,820 -- 108,544	38,736 -- 103,948
Pounds of Lean Pork			
Average	188.93	200.47	201.90
Std Dev	2.74	0.43	0.12
CV	1.45%	0.21%	0.06%
Min -- Max	182.30 -- 201.66	198.62 -- 201.93	201.59 -- 201.95

average standard deviations look similar as well as the distribution of average placements. The deliveries of live hogs to the packer maintained all system models' packer operations at approximately 80 percent capacity utilization. This is equivalent to having the plant operating at full slaughter capacity for five and a half days. The averages and distribution of head delivered under each system model also look similar (Figure 3). On average the vertical integration system reduces relative variability, as measured by the coefficient of variation (CV), by 3 percent below the spot market system.

The coordinated system models are able to consistently deliver leaner live hogs to the packer. To packers, this translates into more pounds of primal cuts per hog delivered. Figure 4 shows the consistency in pounds of lean pork delivered by the coordinated systems. The coordinated systems are able to delay the marketing of less valuable lighter pigs, which yield less usable pounds of lean pork, longer than the spot market system. The vertical integration system's distribution of lean pounds delivered first-order stochastically dominants both the contract and spot market system, and the contract system's distribution of lean pounds delivered first-order stochastically dominants the spot market. Using a coordination mechanism could be viewed as a strategy to reduce the risks associated with physical flows. Of all the physical product flows in the model, the main difference between the three system models is which hogs are sent to the packer. The spot market system sends hogs with less usable pork than the contract and vertical integration systems, highlighting the differing objectives of producers and packers even under a grade and yield grid pricing system.

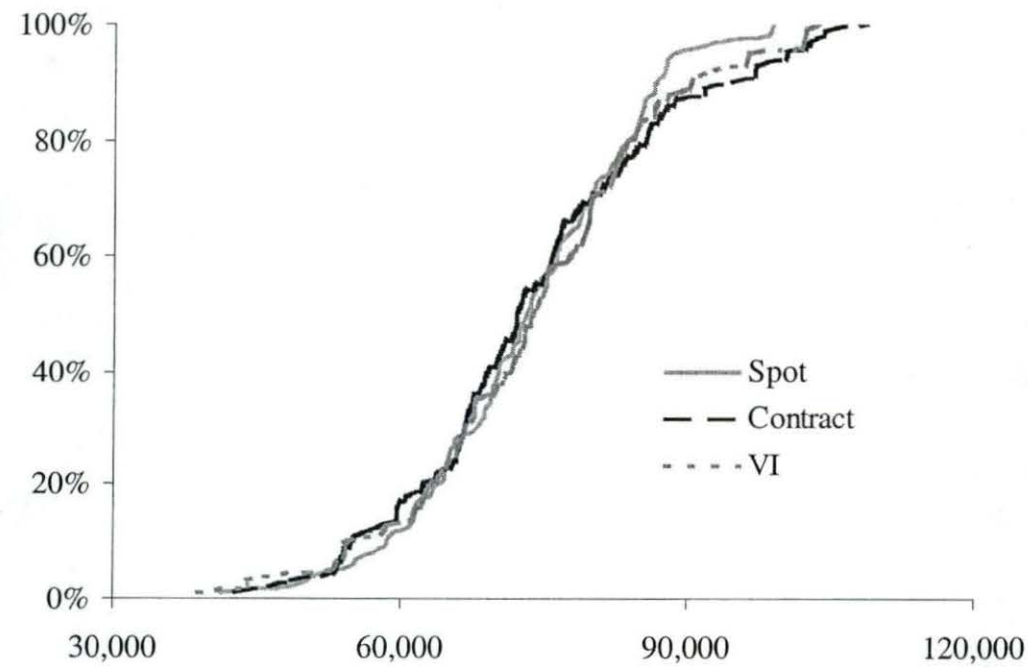

Figure 3. CDF of Average Head Delivered Under Each System Model

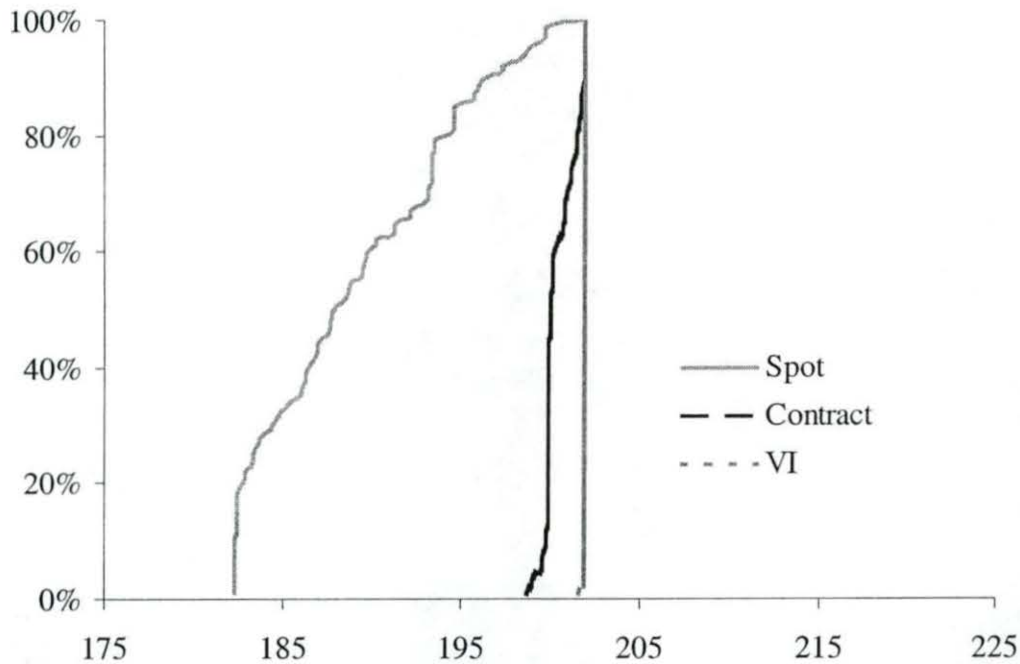

Figure 4. CDF of Average Pounds of Lean Pork Delivered Under Each System Model

Statistical Significance of Differences in Physical Flows

To assess whether statistical differences existed across system models, hypothesis tests were conducted on the average and standard deviation results for pounds of lean pork produced under each coordination system. Standard tests for differences between means and variances are not applicable to the simulated data, the simulated data violate the assumptions of independent distributions. To account for this, Law and Kelton propose a paired t-test for differences between two sample means that does not rely on independence of the samples. Morrison derives a chi-square test statistic to test for homogeneity of within group covariance matrices that is readily computed using discriminant analysis.

Table 2 reports the results of hypotheses tests for differences between the system model's average values and standard deviations for lean pork. The statistical analyses indicate that each coordination system has a statistically significant difference in pound of lean pork. This test indicates that the vertical coordination system will produce a statistically higher average amount of pork primal cuts than either of the other systems resulting in a more efficient use of facilities. In addition, the variability of primal cut pounds will be statistically lower than either of the other coordination mechanism suggesting a more uniform product coming through the packing plant. The combination of more efficiency and uniformity can create a strategic benefit to producers and packers in the vertical coordination system by allowing them to deliver a higher quality more consistent product to the marketplace[2].

[2] This study does not account for any additional premiums that might accrue to systems that have higher quality and more consistent products. However, there are companies that pursue segments of the market that are willing and able to pay premiums for higher quality and more consistent products suggesting that some premiums may exist for vertically coordinated systems.

Table 2. Results of 5% Level Hypothesis Tests for Differences Between Average and Standard Deviation Values for Pounds of Lean Pork Delivered, p-values in Parentheses

	Null Hypothesis			
	H_0^1	H_0^2	H_0^3	H_0^4
	Spot = Contract	Spot = Vert. Int.	Contract = Vert. Int.	Spot=Con=VI
Mean[a]	**Reject** (0.0001)	**Reject** (0.0001)	**Reject** (0.0001)	**Reject** (0.0001)
Standard Deviation[b]	**Reject** (0.0001)	**Reject** (0.0001)	**Reject** (0.0001)	**Reject** (0.0001)

[a]Testing procedure follows Law and Kelton, p. 587
[b]Testing procedure follows Morrison, p. 252

Financial Flows

Financial Flow Performance of Alternative Coordination Systems

The financial performance of each system was measured as returns over variable costs, referred to here as margins. The summary results in Table 3 show that producers in the contract system attain the highest margins of all three systems. Packers clearly favor the vertical integration system as it has the highest packer margins and the lowest risks of all three systems, as measured by the standard deviation and coefficient of variation (CV). At the system level there seems to be little difference among the three systems. While the contract system has the largest expected total margins, they are only slightly better than the vertical integration system.

On average, producers in the spot market system faced over 50 percent relative risk (CV) associated with finishing feeder pigs. This risk was significantly reduced by more than 20 percent in the contract system and eliminated in the vertical integration system (see Table 3). The contract and vertical integration systems also eliminated a lot of the downside risk faced by producers. The CDF of producers' margins illustrates the shifting of the distribution from the spot market to the contract system (see Figure 5) and show that producers have a higher probability of receiving larger margins in the contract system than in the spot market system. While the average producer margins of the spot market and vertical integration system do not differ greatly, the vertical integration system does eliminate the risks associated with finishing feeder pigs (Table 3 and Figure 5). The contract system reduced a large portion of downside risk in producer margins compared to the spot market. The contract system increased the minimum payment from a loss of $69.46 by over $40 to a loss of $28.49. The contract system also increased the probability of margins being greater than zero from 78 percent in the spot market system to 90 percent in the contract system (see Table 3). The vertical integration system provided producers with similar average margins to the spot market and reduced risks beyond that of the contract system. The producer margins show there are gains to be made from using coordination mechanisms other than spot markets.

Table 3. Summary Model Results – Financial Flows (Averages Over 100 Two Year Iterations, negative values in parentheses)

	Coordination Mechanism		
	Spot Market	*Contract $5/Head Bailment*	*Vertical Integration $20/Head Flat Fee*
Producer Margins			
Average	$22.95	$41.20	$20.00
Std Dev	$12.62	$13.28	$0.00
CV	54.98%	32.24%	0.00%
Min – Max	($69.46)--$102.66	($28.49)--$109.37	$20.00--$20.00
P(Margin > 0)	78%	90%	100%
Packer Margins			
Average	$16.29	$4.78	$21.76
Std Dev	$11.06	$11.51	$9.38
CV	67.92%	241%	43.11%
Min – Max	($74.24) -- $93.31	($50.89) -- $63.06	($40.15) -- $79.62
P(Margin > 0)	76%	57%	82%
System Margins			
Average	$39.24	$45.98	$41.76
Std Dev	$8.63	$9.37	$9.38
CV	21.99%	20.37%	22.46%
Min – Max	($9.38) -- $80.13	($9.38) -- $101.98	($20.15) -- $99.62
P(Margin > 0)	98%	97%	98%

The packer did not fare as well as the producer did in the contract system. Comparing the packer's margins in the spot market system to the contract market system the shows margins were reduced more than the $5 bailment from $16.29, in the spot market system, to $4.78, in the contract system. The reduction in returns for the packer is a function of the $5 bailment fee and the packers willingness to pass through any additional value gains associated with access to primal cut marketing information. The assumption of the packer's willingness to pass through marketing gains will be explored further in the next section of the report. The packer's margins in the vertical integration system were larger than in the spot market system and the packer faced less risk in the vertical integration system. The vertical integration system provided the packer with the least exposure to risk -- it had the lowest relative risk of 43.11 percent. It minimized downside risk by truncating the distribution of margins at a loss of $40.15 (see Figures 6 and 7), $10 above the contract system and $34 above the spot market system. The vertical integration system had the lowest occurrence of negative margins (18 percent), 8 percent better than the spot market system and 25 percent better than the contract system (see Table 3).

In general, the packer's margins are more volatile than producer's margins, regardless of the coordination mechanism. However, the packer may be able to reduce volatility in margins by gaining control over its inputs through vertical coordination. This reduction in risk combined with the higher consistency in product attributes from the previous section's analysis maybe the primary reasons for the packing industry's recent push for more vertical coordination.

The system's total margins and risk measures show that all three systems perform similar to one another. The relative risk in each system is about 20 percent and the probability of negative margins occurring is less than 3 percent for each system. The spot market and contract system had identical minimum margins, and they were larger than the minimum margin for the vertical integration system (see Table 3). There is a slight reduction in risk associated with the contract system over both the spot market and vertical integration system, and an increase in average total system margins. From a total system perspective, this indicates that the contract system has advantages over the spot market and vertical integration system by increasing margins and reducing risk.

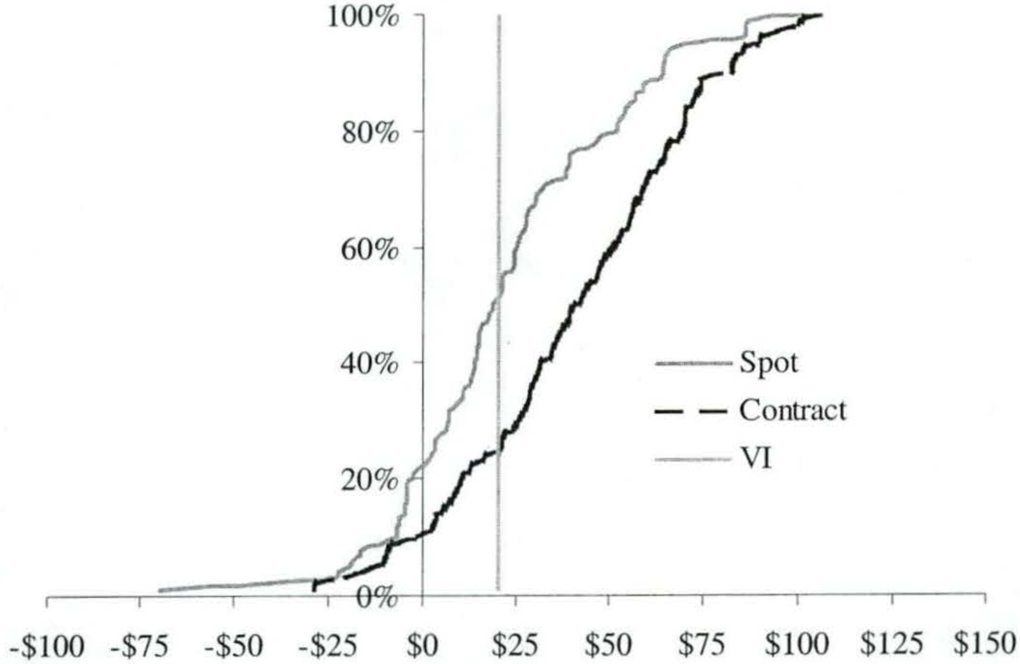

Figure 5. CDF of Average Producer Margins Under Each System Model

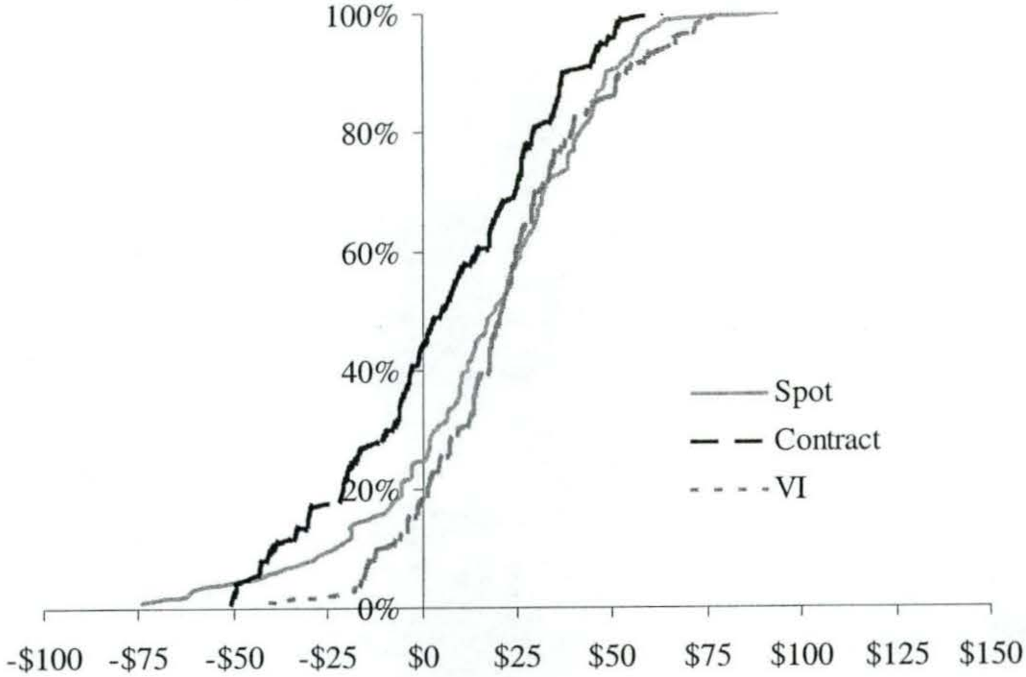

Figure 6. CDF of Average Packer Margins Under Each System Model

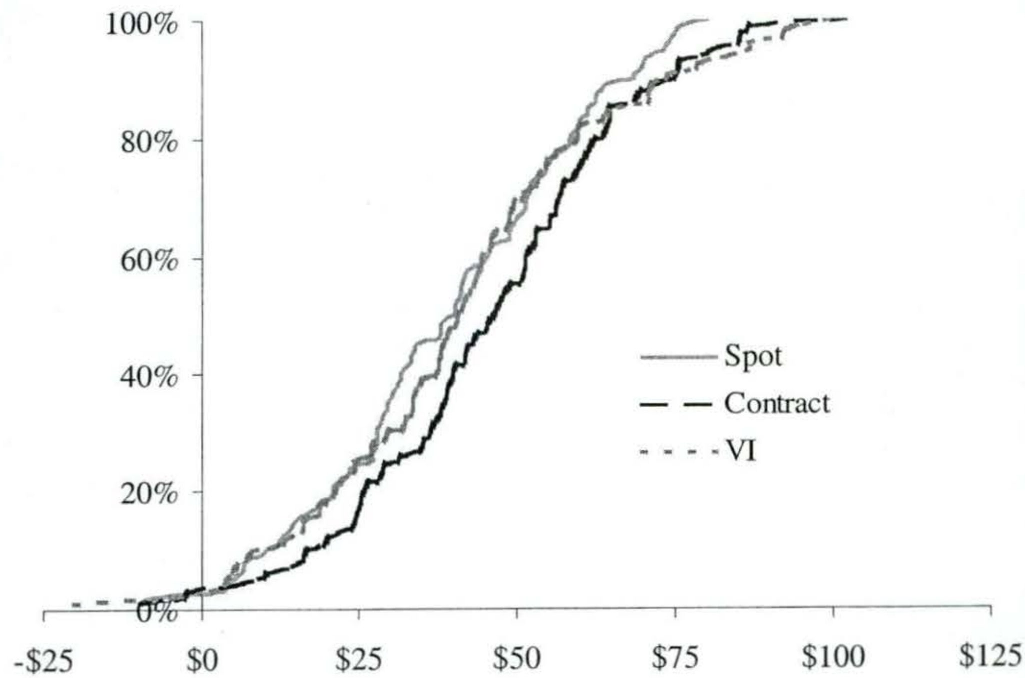

Figure 7. CDF of System Margins Under Each System Model

Statistical Significance of Differences in Financial Flaws

While the models performed similarly at the aggregate system level, there were differences in the allocation of margins to the producers and the packer. To assess whether statistical differences existed in margins across coordination systems, hypothesis tests were conducted on the average and standard deviation results for producer margins, packer margins, and system margins (Table 4). As with the physical flows, standard tests for differences between means and variances are not applicable to the simulated data, the simulated data violate the assumptions of independent distributions. Thus, a paired t-test is used for testing differences between sample means. Morrison's chi-square test statistic for homogeneity of within group covariance matrices was used to test the statistical significance of differences in variability among the three coordination systems.

The Results of the Hypotheses tests suggest that there is not a statistically significant difference in producer margins between the spot market and vertical integration systems. There is, however, a statistical significant difference in producer margins between the spot market and contract system and the contract system and vertical integration system. In terms of packer margins, there was a significant difference in mean margins among all three coordination systems but the direct comparison between the spot markets and contract systems was not significantly different (Table 4). In addition, the hypotheses tests indicate no significant difference in overall system margins between all three coordination systems, although a direct comparison of system margins between spot market and contract systems did result in significantly higher total system margins for the contract system.

Tests for significant differences in variability suggested no significant changes in variability of margins between the spot market and contract coordination. However there were significant differences in margin variability for producers and packers when comparing the spot market to vertical integration (Table 4). In this case the producer's variability is significantly lower and the packer's variability is significantly higher under the vertical integration coordination system. The shift in margin variability between producers and packers results in no significant change in overall system variability under each of the coordination systems. These tests suggest that there is little change in overall system performance from different coordination mechanisms but there is a substantial difference in the risk/reward sharing among participants in the producer/packer sub sector.

Table 4. Results of 5% Level Hypothesis Tests for Differences Between Means and Standard Deviations of Margins, p-values in Parentheses

	Null Hypothesis			
	H_0^5	H_0^6	H_0^7	H_0^8
	Spot = Contract	Spot = Vert. Int.	Contract = Vert. Int.	Spot=Con=VI
Producer Margins				
Mean	**Reject**	**Fail to Reject**	**Reject**	**Reject**
	(0.0001)	(0.3231)	(0.0001)	(0.0001)
Standard	**Fail to Reject**	**Reject**	**Reject**	**Reject**
Deviation	(0.0693)	(0.0001)	(0.0001)	(0.0001)
Packer Margins				
Mean	**Reject**	**Fail to Reject**	**Reject**	**Reject**
	(0.0058)	(0.1543)	(0.0001)	(0.0001)
Standard	**Fail to Reject**	**Reject**	**Fail to Reject**	**Reject**
Deviation	(0.1763)	(0.0041)	(0.1251)	(0.0160)
System Margins				
Mean	**Reject**	**Fail to Reject**	**Fail to Reject**	**Fail to Reject**
	(0.0248)	(0.4251)	(0.1893)	(0.0931)
Standard	**Fail to Reject**	**Fail to Reject**	**Fail to Reject**	**Fail to Reject**
Deviation	(0.2144)	(0.6971)	(0.3935)	(0.4405)

[a]***Testing procedure follows Law and Kelton, p. 587***
[b]***Testing procedure follows Morrison, p. 252***

Motivation for Alternative Coordination Systems

Producers maximize margins in the contract system while the packer maximizes margins in the vertical integration system. To gain a further understanding of the vertical integration systems, the contract and vertical integration system models were solved to determine the minimum and maximum payments required to have both producers and packers enter into a vertically integrated system over a spot market system. These payments are the maximum willingness-to-pay (WTP) and the minimum willingness-to-accept (WTA) a new coordination system. The solutions are restricted such that the risks faced in the newly adopted system are no greater than the spot market system. In the contract system the WTP and WTA payments refer to the bailment payment, and in the vertical integration system the payments are the flat fee producers receive. In this section the spot market system is the status quo system and the alternatives are the contract and the vertical integration systems. Two specific cases are examined, one where producers try to capture the additional gains in the contract system by offering packers a payment in exchange for a marketing contract, and the second case is where packers are trying to convince producers to work for them in the vertical integration system so they can capture the additional margins and risk reduction in the vertical integration system.

Switching from a Spot Market to a Contract Market System

In the first case producers are trying to entice packers to offer them a marketing contract. This would enable the producers to increase their margins and reduce the risks they are facing in the spot market system. How much would producers be willing to pay the packer to offer them a marketing contract, and what compensation would packers ask for if they offered a marketing contract?

Producer's Maximum WTP for the Contract System

The contract system model was solved for the producer's maximum WTP. The results from running the contract system model with the packer receiving a payment of $12.05 (producer's maximum WTP) are given in Table 5 in the middle column labeled "*Payment of $12.05 (Max Producer WTP)*." The results indicate that the producer would be willing to pay (or forfeit) $12.05 per head in exchange for a marketing contract with the packer. The marketing contract would provide producers with additional risk reduction over the spot market system. While the relative risk faced by producers is nearly identical, their downside risk is truncated, as shown by the higher minimum. Packers would face less relative risk and also benefit from a truncation of downside risk. The producer's probability of negative margins increases slightly from 32 percent in the spot market system to 34 percent in the contract system while the packer's probability of negative margins is unchanged. The packer's margins increase by more than $5, and they lower their relative risk by 10 percent from 67 percent in the spot market system to 57 percent in the contract system. In addition the packer decreases their lowest margin in the new contract system from a loss of $74 in the spot market system to a loss of $33 in the new contract system. With producers offering $12.05 the packer has economic incentives to offer a marketing contract in return. This arrangement brings about a Pareto improvement for the entire system and all the participants.

Table 5. Willingness to Pay and Accept Switching from a Spot Market to a Contract System

	Spot System	*Contract System*	
		Payment of $12.05 (Max Producer WTP)	*Payment of $7.17 (Min Packer WTA)*
Producer Margins			
Average	$22.95	$24.15	$29.03
Std Dev	$12.62	$13.28	$13.28
CV	54.98%	54.98%	45.75%
Min	-$69.46	-$45.54	-$40.66
Max	$102.66	$92.32	$97.20
P(Margin > 0)	78%	76%	79%
Packer Margins			
Average	$16.29	$21.83	$16.95
Std Dev	$11.06	$11.51	$11.51
CV	67.92%	57.21%	67.89%
Min	-$74.24	-$33.84	-$38.72
Max	$93.31	$80.11	$75.23
P(Margin > 0)	76%	76%	73%
System Margins			
Average	$39.24	$45.98	$45.98
Std Dev	$8.63	$9.37	$9.37
CV	21.99%	20.37%	20.37%
Min	-$9.38	-$9.38	-$9.38
Max	$80.13	$101.98	$101.98
P(Margin > 0)	98%	97%	97%

Packer's Minimum WTA the Contract System

The previous section determined producers' maximum WTP for a contract offer. But would the packer really need the entire maximum WTP to convince them to offer a marketing contract? The packer's minimum WTA a contract offer was calculated, and the results from running the contract system model with the packer receiving a payment of $7.17 (packer's minimum WTA) are given in Table 5 in the last column on the right labeled, "*Payment of $7.17 (Min Packer WTA)*." The results that the producers' average margins are just as large as when they were offering $12.05 to the packer, and now when they only have to offer $7.17 they face less relative risk. The packer's outcomes are similar to their spot market outcomes with the exception that the contract with the packer's minimum WTA eliminates some of the downside risk by truncating the downside risk of margins.

These results show that there is a potential for feeder pig finishing to become coordinated through the use of a contract mechanism. This outcome is stable in the sense that it offers a

Pareto improvement for both producers and the packer. The producer's maximum WTP being greater than the packer's minimum WTA provides a range over which negotiation would occur. Any contract offer with a payment outside this range would result in one of the parties either not accepting the offer or the offer not being made at all.

Spot Market to Vertical Integration System

The second scenario considered has the packer attempting to recruit the producer to work for them in a vertical integration system. At the system level there is no clear motivation in terms of average margin improvement or significant risk reduction, but there are advantages to both producers and the packer in terms of reducing their individual risks (see Table 3). Alternatively packers may be motivated by the opportunity to improve their lean pork product flows. Specifically how much would packers be willing to pay producers to work for them and how much would producers ask for?

Packer's Maximum WTP for Vertical Integration

First, the contract model was solved to determine the packer's maximum WTP. The maximum WTP was $25.47 per head finished (Table 6). This offered little improvement in financial flows for the packer, but did reduce the relative risk they faced and truncated their distribution of margins, thus reducing risk relative to the spot market system. Producers were able to increase their average margins and reduce risks at the same time. Producers no longer can capture any of the upside potential in their margins. The probability that producer margins exceeded $25.47 in the spot market system was 40 percent, or 60 percent of the time producers in the spot market would have margins less than the vertical integration system with a $25.47 flat fee. Even with packers offering their maximum WTP there are quantifiable economic benefits to both producers and packers who coordinate through the use of a vertical integration mechanism.

Packer's Minimum WTA Vertical Integration

The minimum WTA flat fee the producer would require to switch from the spot market system to the vertical integration system was $22.95. As with all previous solutions, it was imposed that the producer be left no worse off in terms of their average margin and the risks faced. The results for the producer are given in the middle column of Table 6; the producer requires that the flat fee be at least as good as the spot market average margins or $22.95. Under this vertical integration system the producer would be forfeiting any margins that exceeded $22.95, which occurred 45 percent of the time, in exchange for a stable flow of margins. The packer's average margins increase and they face less relative risk compared to the spot market system. The packer also eliminates of some downside risk and shifting of the distribution of margins.

Table 6. Packer's Offer to Move from a Spot Market to a Vertical Integration Market System

	Spot System	*Vertical Integration System*	
		Flat Fee of $22.95 (Min Producer WTA)	*Flat Fee of $25.47 (Max Packer WTP)*
Producer Margins			
Average	$22.95	$22.95	$25.47
Std Dev	$12.62	$0.00	$0.00
CV	54.98%	0.00%	0.00%
Min	-$69.46	$22.95	$25.47
Max	$102.66	$22.95	$25.47
P(Margin > 0)	78%	100%	100%
P(Margin > $22.95)	45%	-	-
P(Margin > $25.47)	40%	-	-
Packer Margins			
Average	$16.29	$18.81	$16.29
Std Dev	$11.06	$9.38	$9.38
CV	67.92%	49.87%	57.58%
Min -- Max	-$74.24	-$43.10	-$45.62
Max	$93.31	$76.67	$74.15
P(Margin > 0)	76%	78%	75%
System Margins			
Average	$39.24	$41.76	$41.76
Std Dev	$8.63	$9.38	$9.38
CV	21.99%	22.46%	22.46%
Min — Max	-$9.38	-$20.15	-$20.15
Max	$80.13	$99.62	$99.62
P(Margin > 0)	98%	98%	98%

These results suggest that there are incentives for both producers and packers to coordinate using a vertical integration mechanism. There is a flat fee payment range of $22.95 to $25.47 over which this system would exist. The difference in the WTA and WTP would be the range over which individual producers and the packer negotiate.

Chapter 4: Conclusions

Results and Conclusions

The results of this empirical analysis of various coordination mechanisms (spot market, contract, vertical integration) between producer and packer in the pork industry suggest a number of conclusions. First, coordination systems that are more closely aligned do not necessarily result in more hogs marketed and slaughtered, but they do provide the information and incentives to produce and market hogs that yield more usable pounds of primal cuts than the spot market system. The vertical integration system markets live hogs that yield the most usable pounds of primal cuts. And, in the vertical integration system, hog marketings have the lowest variability of all three systems. The contract system marketed hogs that yielded less usable primal cuts compared to vertical integration, but the difference was small. The spot market system marketed hogs that yielded on average 10 pounds fewer primal cuts than both the contract and vertical integration system, and it did so with increased variability.

The analysis of total system, producer and packer margins showed that there were measurable differences between the system models. The spot market model generated lower system margins compared to the contract system and vertical integration system models which had similar total system margins. What differed between the contract and integrated system was the way in which the system margins were distributed to the producers and packer. Producers capture significantly more of the total system margin under the contract arrangement than the $20/head fee allocated to the production division under a vertically integrated system.

In general, the model results indicated that the spot market system margins and the vertical integration system margins were highly similar; statistical tests of the averages and standard deviations indicated that the producer, packer, and system margins were equivalent. The contract system margins were different from both the spot market and vertical integration system margins; the contract system had larger producer margins and smaller packer margins relative to both the spot market and vertical integration systems.

These results suggest the following conclusions:

9. The choice of coordination mechanism doesn't alter total system performance dramatically as measured by margins and their volatility, but the coordination mechanisms differ in how they distribute the risks and returns to producers and the packer.
10. Spot markets and contracting had the same variability associated with producer margins, as the marketing contract arrangements modeled were intended to only provide market access and not reduce risks.
11. Marketing contracts did not offer packers any margin risk reduction over spot markets, but they did increase the pounds of usable pork per hog delivered and reduced the variability of the pounds of usable pork per hog delivered compared to the spot market.
12. The largest gains from better coordination come from placing and marketing the feeder pigs that will produce more primal cuts and little additional value is added from just coordinating live hog physical flows.

13. For the packer the spot market and vertical integration system had equivalent margins, but the vertical integration system had the lowest relative volatility associated with margins.
14. For the packer the lowest average margins and highest average volatility of margins were realized from using contracting.
15. Contracting offers producers the highest margins on average, while vertical integration eliminates all risks associated with producer margins.
16. Producers deciding between the spot markets and contracting can receive higher margins and reduce margin volatility with contracting.

Analysis of the minimum willingness to accept and maximum willingness to pay measures that reflect producers and packers willingness to participate in a contract system and in a vertical integration system suggest that there are economic and financial benefits for both producers and packers to reorganize from a spot market coordination system to a more closely aligned contract or vertical integration coordination system. More specifically these results indicate that:

- Spot market producers are willing to forfeit up to $12.05 per head in exchange for a marketing contract from the packer.
- Packers buying on the spot market would not offer a marketing contract unless it provided them with an additional $7.17 per head.
- Contract arrangements that create Pareto improvement for both producers and packers relative to the spot market are possible if they can be negotiated between the packers' minimum requirement of $7.17 per head and the producers' maximum willingness to forfeit of $12.05 per head.
- To be part of a vertically integrated system, producers would require a flat fee of at least $22.95 per head delivered.
- Packers buying on the spot market are willing to pay up to $25.47 per head as a flat fee to producers who choose to produce in a vertically integrated system.
- A Pareto improvement for both producers and packers would exist if a fee between $22.95 and $25.47 (paid by the packer) could be negotiated for the producer to be a participant in the vertically integrated production system.
- There was not a payment range over which producers and the packer would negotiate to move from the contract system to the vertical coordination system.

Limitations and Future Research Directions

This study is one of the first attempts to numerically quantify the physical and financial impacts of alternative mechanisms for coordination in the food production and distribution industry. The specific focal point of this study has been different coordination arrangements between producers and packers in the pork industry; the coordination arrangements analyzed included open spot markets, contracting and vertical integration. The opportunities for further research are numerous and include the following:

1. Evaluation of additional coordinating structures with a specific focus on different contracting arrangements including production, marketing and resource providing contracts that include performance bonuses or offer incentives for more efficient production.
2. Extending the analysis through further steps in the supply chain beyond the producer and packer linkage to include downstream activities such as processing and retailing and upstream activities including genetics, breeding and feeder pig production.
3. Assessing the impacts of alternative pricing grids that provide the mechanism to transmit value information about primal cuts to producers in market coordinated systems.
4. Develop an aggregate or industry model that might be structured similar to that used here which will generate sector level results to answer questions concerning size, structure and coordination mechanisms for the pork value chain.
5. Include dynamic adjustment processes in the model which allow participants to make investments and alter production capacity in both the feeder pig production and packing sectors.

Although the modeling used in this study has significant merit, further work with this similar modeling activity should respond to the following problems:

1. Cost information for the packing industry in particular is difficult to obtain, and additional data is necessary to verify cost of slaughter and pork packing activities.
2. The state space modeling for feeder pig placements does not directly link output markets with input supply and demand, and some form of an equilibrium model that explicitly makes this linkage would be preferred.
3. Specification of separate input and output market price models does not allow full reflection of opportunities to exercise market power and other market irregularities; this concern might again be addressed with a generalized equilibrium model.

Appendix A: Detailed Methodology

Previous literature has demonstrated the ability of system modeling to incorporate dynamic effects from optimal decision-making and provide information about the evolution of the system being studied. Empirically quantifying these impacts will provide information about the contributions of coordination mechanisms to the overall producer-packer system performance. Prior studies and surveys have illustrated that the motivation for increased coordination is coming from two different sources. Producers seek to secure market access and packers want to gain control over their inputs. Both are looking to improve their economic and financial performance in an industry that is experiencing structural changes. To address these issues this research will develop a stochastic sequential mathematical programming model of optimal producer and packer decision-making in the pork production and packing system.

The model will build on previous research that has focused on similar but different aspects of production and packing. Production and packing will maximize returns over variable costs (Shah, Okos, and Reklaitis). Producers activities will consist of finishing feeder pigs and marketing finished hogs. Packers activities include procuring live hogs, determining P&D schedules, storing and selling primal pork cuts. The input and output markets for producers and packers will incorporate dynamic market effects (McCarl and Spreen; Onal et. al.; and Spreen, McCarl, and White). Unlike the price endogenous models that model systems at the sector level, this research will focus on an individual packer and a group of producers in a close geographic region. Market dynamics will be modeled using multivariate time series models. Where price endogenous models solve for input and output prices given sector supply and demand, the model used here will rely on the time series model to account for the market dynamics. The results from the methodology used in this research are similar to the price endogenous model, where both producers and the packer are price takers in their input and output markets.

This research develops three dynamic system models of hog production and packing and measures the impacts associated with three different coordination mechanisms through simulation of the system on a weekly basis over a two-year period. The three system models are differentiated based on the coordination mechanisms used between production and packing. The three coordination mechanisms analyzed are spot market coordination (SM), contract coordination (CC), and vertically integrated coordination (VI).

For the purposes of this research, spot market transactions are defined as sales between the production and packing sector where the only transfer of information is a premium and discount grid for weight and leanness characteristics. Neither the production nor the packing sub-sector has any influence on the base price paid for live hogs and the packer buys all pigs marketed by the producers. Contract market transactions are sales of live hogs from the production sub-sector to the packing sub-sector by means of pre-arranged sales contracts. The contracts are "shackle space" agreements that assure producers of a place to market live hogs. The producers own the hogs while they are in the finishers and transfer ownership with their sale. The contract design is such that producers are paid a fixed payment per hog delivered in addition to the market price for live hogs plus (less) any premiums (discounts) for weight and leanness characteristics. The premium and discount schedule is identical to the spot market. In the contract system the packer has a call option for delivery on the live hogs and guarantees that all hogs will be marketed within a fixed period of time. In the vertical integration system, the packer owns the live hogs throughout and thus makes the sole determination as to when they are transferred from production to packing.

Model Overview

There are five main components to the system model. The components are: feeder pig placement, biological growth, live hog marketing, primal cut sales/storage of packer operations, and input/output market prices. The model begins with the placement of feeder pigs determined by a stochastic process. The feeder pig placement stochastic process is modeled using state-space time series techniques. Separate feeder pig placement models were used for each of the system models reflecting the alternative coordination mechanism structures. Feeder pigs mature into market weight hogs according to biological growth equations similar to those used by Craig and Schinckel and have two unique characteristics, weight and leanness. Market weight hogs are then sold, according to the live hog marketing model used for each coordination mechanism, to packers who transform live market weight hogs into six primal cuts: hams, bellies, loins, picnics, ribs, and butts. The live hog marketing models determine when and which hog types (weight and leanness categories) to market based on availability from previous periods feeder pig placements. The packer is modeled as a profit maximizer and solutions to the packer's problem provide primal cut sales and storage activity along with live hog shadow prices used to construct subsequent period's P&D schedules.

The feeder pig placement and biological growth model will be simulated on a weekly basis over a period of two years for 100 iterations to determine inputs to the live hog marketing model. The live hog marketing and primal cut sales/storage models are then solved sequentially given the simulated inputs. The outputs from these models are optimal marketings of live hogs and optimal sales of primal cuts. The packer's behavior is specified by each coordination mechanism and prohibits them from exhibiting any form of non-competitive behavior. Additionally, the use of the state-space input and output market price models further restricts both producers and the packer from exploiting market power.

Feeder Pig Placement

A stochastic process for each coordination mechanism determines the placements of feeder pigs. The models of feeder pig placements (FPP) are a function of the information set that each coordination mechanism decision-making model uses. To capture the differences in FPP among the three coordination mechanism models, three different models of FPP were estimated.

Feeder Pig Placement in the System's Models

The first FPP model is for a spot market system and does not utilize any additional price information beyond what is contained in the P&D schedule or use any method of product flow scheduling. Placements in the spot market system were determined by the equation FPP_t^{SM}, which is a function of the information used by the hog production sector when delivering to the spot market. In this research it is assumed that FPP in the spot market are a function of input prices (feeder pigs (P_t^{FP}), corn (P_t^{C}), and a 6-month interest rate (i_t^{6})), output price (live hog futures price (P_{t+15}^{LH})), and the capacity of sows supplying feeder pigs. Additionally, FPP_t^{SM}

depends on the uncertainty of the live hog price that will be paid when the current batch of feeder pigs reaches market weight.

$$FPP_t^{SM} = f\left(sows_t, P_t^{FP}, P_{t+15}^{LH}, \sigma_{t+15}^{LH}, P_t^{C}, i_t^{6}\right) \tag{1}$$

The second model of FPP is for a contract coordinated system and is given by equation FPP_t^{CC}. The information set available to contract coordinated production includes the FPP_t^{SM} information set and additional information coming from the packers output market (primal cut market). Coordinating production and packing establishes a link between the feeder pig, live hog, and primal cut markets that previously did not exist in the spot market model. The additional information in the FPP^{CC} model relates to each of the *i* (hams, loins, bellies, picnics, ribs, and butts) primal cut prices ($P_{i,t}^{PC}$), the storage level of each primal cut ($QS_{i,t}^{PC}$), and the uncertainty or volatility of each primal cut price ($\sigma_{i,t}^{PC}$).

$$FPP_t^{CC} = f\left(sows_t, P_t^{FP}, P_{t+15}^{LH}, \sigma_{t+15}^{LH}, P_t^{C}, i_t^{6}, P_{i,t}^{PC}, QS_{i,t}^{PC}, \sigma_{i,t}^{PC}\right) \tag{2}$$

The third model of FPP is for a production-packing system that is vertically integrated. In this system the packer owns the production sector and thus raises packer-owned hogs from feeder pigs. The vertically integrated packer exclusively demands and supplies the entirety of the packer-owned hogs. This decouples the link between the live hog market and the corresponding vertically integrated system used to determine feeder pig placements. FPP for a vertically integrated system are given by the following equation FPP_t^{VI}.

$$FPP_t^{VI} = f\left(sows_t, P_t^{FP}, P_t^{C}, P_{i,t}^{PC}, \sigma_{i,t}^{PC}, i_t^{6}, QS_{i,t}^{PC}\right) \tag{3}$$

Estimation of Feeder Pig Placement Models

The stochastic processes for FPP described above were estimated using a multivariate time series technique known as state-space modeling. State-space time series models are dynamic and utilize *states*, or dynamic factors, to discover the underlying common dynamics between related series. When using state-space techniques, the difficulty of modeling large numbers of complicated time paths is reduced by the orderly inclusion of sample information and is robust with respect to the number of states (Aoki and Havenner). "Time series may be viewed as being generated by systems which transform information contained in past and present exogenous signals into future observations (Luo)." State-space models are able to capitalize on this learned information and correct themselves over time.

The state-space representation used here is referred to as the innovation form and closely follows the development of state-space models by Aoki and Aoki and Havenner. The basic system of equations is:

$$Z_{t+1} = \mathbf{A}Z_t + \mathbf{B}\varepsilon_t \tag{4}$$

$$Y_t = \mathbf{C}Z_t + \varepsilon_t \tag{5}$$

where **A**, **B**, and **C** are the coefficient matrices that are estimated, Z is the state variable, Y is the data generating process being modeled, and ε is an error vector with zero mean and constant variance-covariance. Equation (4) is the state or dynamic equation and equation (5) is the observation equation. The state equation describes the dynamics of the system while the observation equation relates the state variable to the data generating process and describes the stochastic process.

In state-space modeling, the rank of the Hankel matrix (**H**) determines the model dimension, or size of the state-space. The Hankel matrix consists of the stacked vectors of future observations (Y_{t+f}) and past observations (Y_{t-p}), where $f = 0, 1, 2, \ldots, n_f$ and $p = 1, 2, 3, \ldots, n_p$. The Hankel matrix is defined as:

$$\mathbf{H} = E\left(Y_{t+f} Y'_{t-p}\right) \tag{6}$$

The rank of the Hankel matrix also determines the dimensions of the coefficient matrices **A**, **B**, and **C** to be estimated. The estimates of the coefficient matrices are closely related to the singular vector associated with the included singular values. The resulting leading principal coefficient sub-matrices will always be those related to the largest singular values (Luo). This ensures that the most influential states will be included in the final model, a characteristic that provides state-space models robustness with respect to the number of states. In the case of model misspecification, when additional states are added, the existing coefficient matrices will not change, and if there are omitted states the most important ones will be included.

State-Space Feeder Pig Placement Estimation

The feeder pig placement models in equations (1), (2), and (3) were estimated following the developments of Aoki and Aoki and Havenner. Summary results are presented in Table A1. All models had high squared correlations between actual and predicted values in excess of 0.99 and the in-sample plots of the actual values. The predicted values are in Figures A1, A2, and A3 along with plots of each models forecast errors. Each model was able to accurately predict the feeder pig placement up and down turns, and the models predicted magnitude well. Thus, there is strong evidence of correctly functioning models when the summary statistics and visual performance measures are this good with volatile series and when large multivariate models are used (Aoki and Havenner). The plots of the forecast errors do not show any systematic patterns and give strong indication that they are white noise error terms, see figures (A1), (A2) and (A3).

Table A1. State Space Model Results for the Feeder Pig Placement Equations

Series	*Mean*	*RMSE*	*Squared Correlations*[a]
FPP^{SM}	42,447	541.33	0.9989
FPP^{CC}	60,504	528.75	0.9993
FPP^{VI}	60,504	494.23	0.9994

[a]Squared correlations between actual and predicted values are used as an analog to R^2

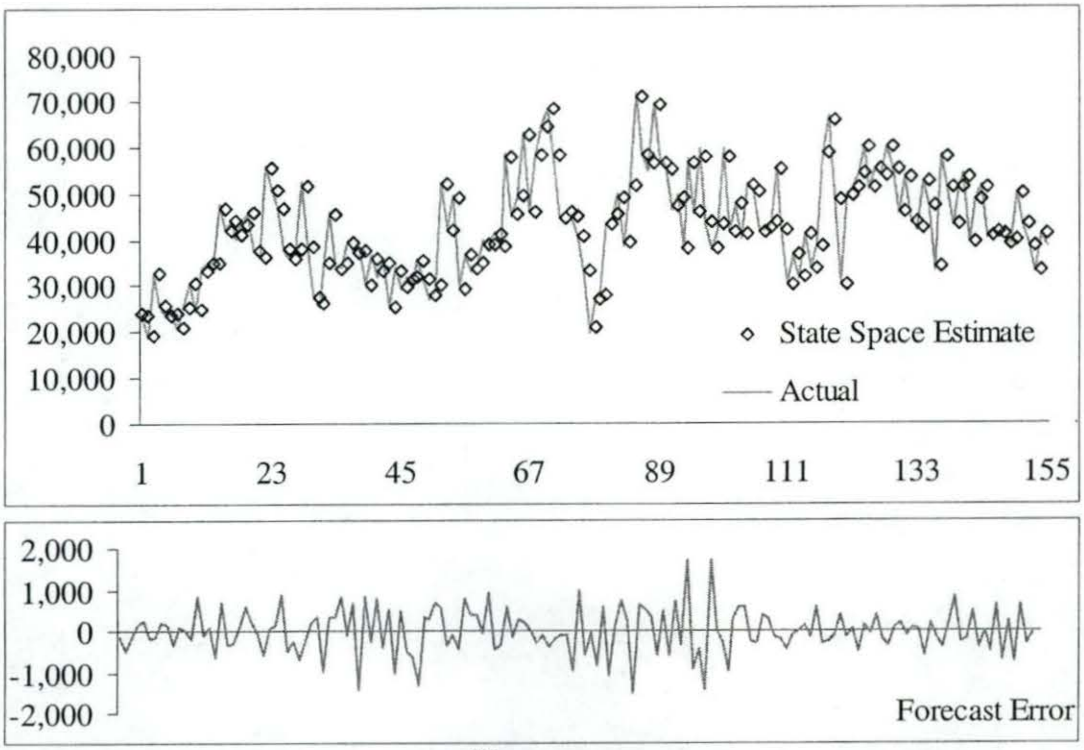

Figure A1. State Space Estimation of FPP^{SM} Equation: Actual, Estimate, and Errors

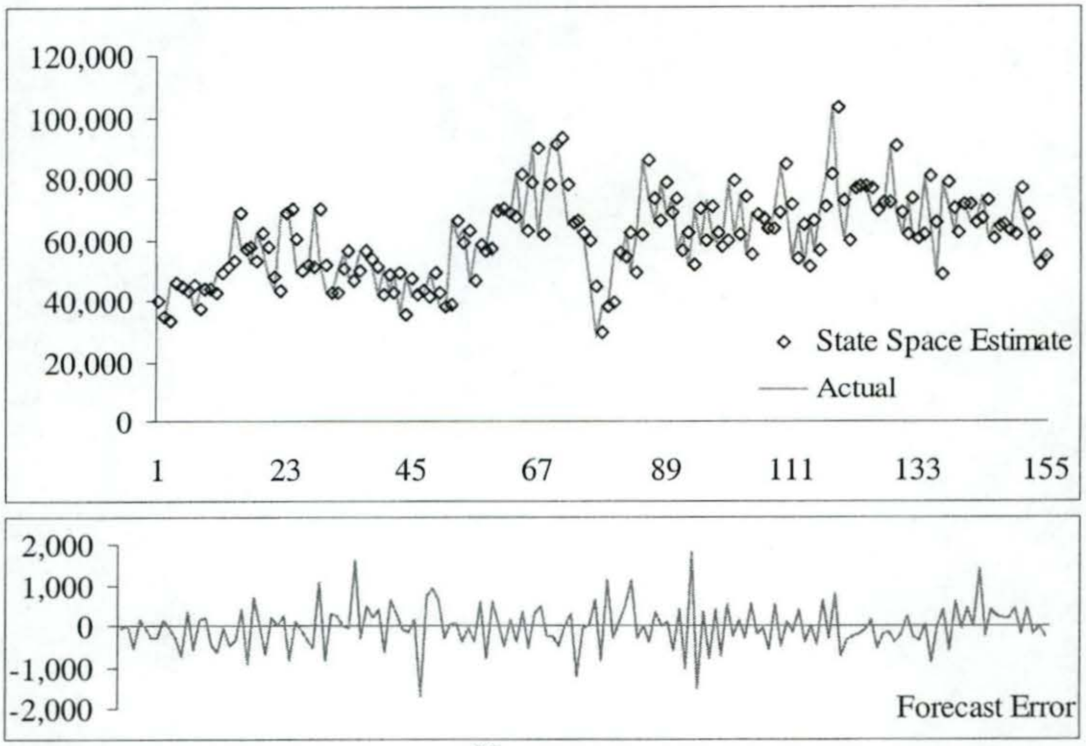

Figure A2. State Space Estimation of FPP^{CC} Equation: Actual, Estimate, and Errors

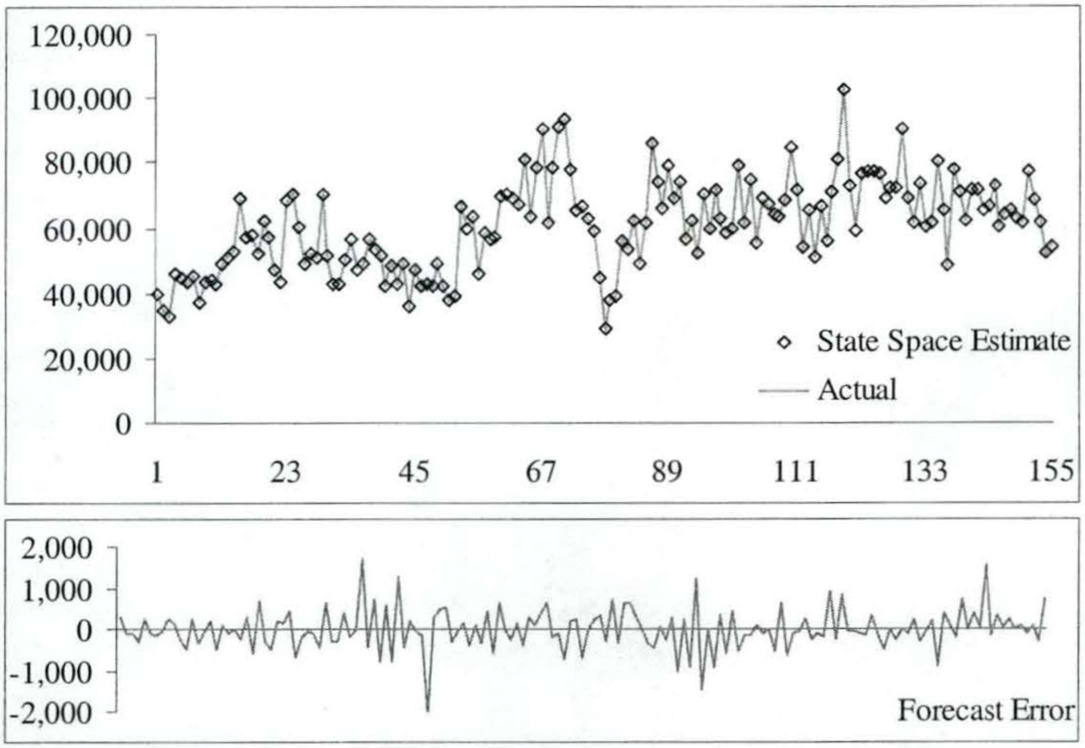

Figure A3. State Space Estimation of FPP^{VI} Equation: Actual, Estimate, and Errors

Simulating Feeder Pig Placement

In each of the coordination mechanism models the estimated state-space models were simulated to provided feeder pig placements and prices for each system. With the coefficient matrices, estimated future values of Y were simulated using the following system:

$$Z_{T+n+1} = \hat{\mathbf{A}} Z_{T+n} + \hat{\mathbf{B}} \tilde{e}_{T+n}. \tag{7}$$

$$Y_{T+n} = \hat{\mathbf{C}} Z_{T+n} + \tilde{e}_{T+n}. \tag{8}$$

Where $\hat{\mathbf{A}}, \hat{\mathbf{B}}$, and $\hat{\mathbf{C}}$ the estimated coefficient matrices and $\tilde{e}_{T+n}$ is the random error disturbance term in period $(T + n)$. The random error terms generated are correlated mean zero error terms. This method of simulation implies that the random error terms are contemporaneously correlated by the simulation procedure and then serially correlated through the estimated state space model.

<u>Biological Growth Model</u>

The live hog production model incorporates uncertainties that arise from the biological growth of live hogs, stochastic base price paid for live hogs, and the packer determined carcass merit schedule. Live hog production will be simulating by modeling feeder pig growth as a function of target weight and days on feed. The biological growth model raises live hogs to market weight (200 to 300 pounds live weight) from feeder pigs that enter finisher barns at approximately 50 to 60 pounds in live weight or around 50 days in age. Swine growth models that integrate the knowledge of genetic potential, nutrient intake, and environmental conditions on pig growth can be used to identify alternative strategies for pork production (Craig and Schinckel). To more accurately account for growth a nonlinear mixed effects model of swine growth was used. Craig and Schinckel estimate a Bridges weight function (WT_i) for weight gain and a fat free lean index function (FFL_i) for fat free lean weight gain of the following form:

$$WT_{i,t} = \left(C^w + c_i^w\right)\left\{1 - \exp\left(-b_0^w t^{b_1^w}\right)\right\} + e_{i,t}^w \tag{9}$$

$$FFL_i = \left(C^f + c_i^f\right)\left\{1 - \exp\left(b_0^f + b_1^f WT_i + b_2^f WT_i^2\right)\right\} + e_{i,t}^f \tag{10}$$

where C^w is the average mature weight from the weight equation, c_i^w is the random weight effect for pig i, t is the time on feed in days, $e_{i,t}^w$ are the deviations of animal i's weight at time t from the mean. C^f is the average mature weight from the fat free lean index equation, c_i^f is the random fat free lean effect for pig i, $e_{i,t}^f$ is the deviation of animal i's pounds of lean body mass (leanness) at time t from the mean leanness, and $b_0^w, b_1^w, b_0^f, b_1^f$, and b_2^f are the coefficients to be estimated. The random effects, c_i's, and residuals, $e_{i,t}$'s, are assumed to be independent. The nonlinear mixed effects model accounts for variability both within and between pigs in a group (Craig and Schinckel).

Estimation of Biological Growth Equations

Data was collected from feeding trials for 128 barrows grown in a segregated early wean environment at Purdue University by the Animal Science Department. Equations (9) and (10) were fit to a non-linear mixed effects model (Schickel and Craig). The fitted equations are given in equations (11) and (12).

$$WT_i = 367.29\left\{1 - \exp\left(-6.1\text{x}10^{-5} t^{1.97}\right)\right\} \tag{11}$$

$$FFL_i = 254.46\left\{1 - \exp\left(1.05\text{x}10^{-2} - 1.89\text{x}10^{-3} WT_i + 2.7\text{x}10^{-6} WT_i^2\right)\right\} \tag{12}$$

The fitted equations define each hog with two unique characteristics: live weight and leanness as a percentage of live weight. Both characteristics are functions of the days on feed in the finisher barns. The fitted biological growth equations (11) and (12) are plotted in Figure A4.

Simulating Biological Growth

The output of the biological growth model is a joint distribution of live hogs based on live weight and leanness. For simplicity, the weight and leanness ranges were reduced to four weight classes and three leanness ranges. This gives twelve possible market hog types. Table A2 below gives the weight and leanness categories along with the hog types used in this research.

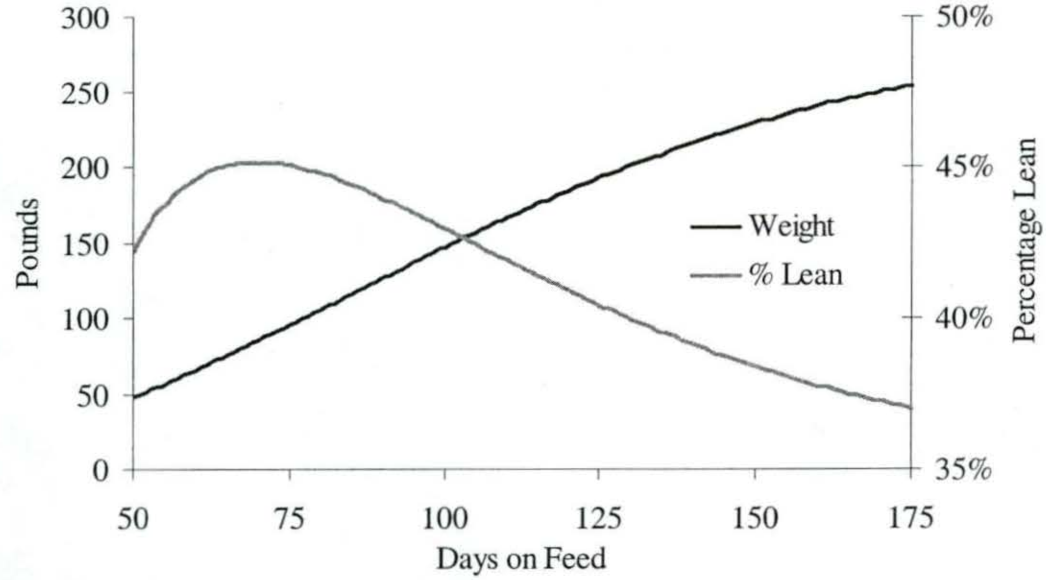

Figure A4. Estimated Weight and Lean Biological Growth Functions

Table A2. Labels for the Categories of Hog Types by Live Weight and Live Weight Percent Leanness

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	1	2	3
225 to 250	4	5	6
250 to 275	7	8	9
275 to 300	10	11	12

To simulate feeder pig growth, over time, distributional parameters from the fitted non-linear mixed effects models were used for specify distributions for the stochastic variables in equations (11) and (12). The distributions were used to simulate the stochastic variables given in equations (13) and (14). Together equations (11), (12), (13), and (14) were used to simulate feeder pig growth into one of the twelve hog types over time.

$$c_i^w \sim N(0.00, 35.89) \qquad e_i^w \sim N(0.00, 2.80) \qquad (13)$$

$$c_i^f \sim N(0.00, 36.21) \qquad e_i^f \sim N(0.00, 2.78) \qquad (14)$$

The simulation of feeder pig growth was used to provide population information rather than information on each individual pig since hog delivery in the system models is based on load averages rather than individual hog characteristics.

The above hog growth equations and stochastic parameter distributions were simulated for three lengths of time on feed (t). In the first period the time on feed was set at 13 weeks and equations (11) and (12) were simulated 500 times[3]. The simulation results were used to generate a discrete distribution over the twelve hog types. The results from the 13 weeks on feed simulation are in Table A3. Over one third of the feeder pigs grew to the 225 to 250 weight category, 48% to 52% leanness category. The simulation procedure was then repeated for $t = 14$ and $t = 15$. The results from the simulations were again used to generate discrete distributions for market weight hog characteristics and are given in tables A4 and A5.

Table A3. Distribution of Hog Types After 13 Weeks on Feed (G_{13})

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.70%	5.70%	2.63%
225 to 250	15.21%	35.22%	3.15%
250 to 275	17.95%	12.11%	0.54%
275 to 300	6.12%	0.66%	0.00%

Table A4. Distribution of Hog Types After 14 Weeks on Feed (G_{14})

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.19%	1.61%	0.93%
225 to 250	5.66%	16.61%	2.15%
250 to 275	28.11%	24.83%	1.50%
275 to 300	16.10%	2.29%	0.01%

Table A5. Distribution of Hog Types After 15 Weeks on Feed (G_{15})

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.11%	0.87%	0.35%
225 to 250	1.32%	5.93%	1.01%
250 to 275	26.13%	24.70%	1.84%
275 to 300	32.38%	5.32%	0.02%

Biological Growth Dynamics

The distributions of hogs after 13, 14, and 15 weeks on feed in the finisher barns defined previously are valid when hogs are kept on feed for the entire period. When making marketing decisions it may be more profitable to sell a specific hog type today and keep the remaining hogs on feed for additional weeks. Or conversely, selling certain hog types at different times could minimize losses. Two conditions were imposed that ensured hogs of declining value were sold as soon as possible. The least lean hogs (categories 1, 4, 7, and 10) and the heaviest hogs (categories 10, 11, and 12) are not able to gain value over time with the growth equations used.

[3] Convergence (less than 0.5% change) of the output distribution for all three times on feed simulations occurred prior to 500 iterations.

These equations do not allow for hogs to lose weight or fat body mass over time. In any period all hogs in both of these categories will be marketed.

To incorporate growth dynamics the weight and leanness transition distributions were derived from equations (9) and (10). The derivative of equations (9) and (10) were taken with respect to time and evaluated at the categorical break points and are given in equations (15) through (19). The dynamics of weight gain over time are given by equations (15) and (16). Weight gain was calculated for two intervals: 13 and 14 weeks on feed in the finisher barns. The model setup is such that no hogs remained on feed after 15 weeks. The dynamics for hog leanness over time are given by equations (17) through (19). The subscripts in equations (17) through (19), $i \rightarrow i+1$, refer to the change in leanness associated with a change in weight from category i to $i+1$. Both sets of weight and leanness changes over time quantify what was illustrated in figure 11, that the lean composition of a hog declines at a decreasing rate and the weight gain of a hog increases at a decreasing rate.

$$\left.\frac{dWT}{dt}\right|_{t=13wks} = 10.56 \tag{15}$$

$$\left.\frac{dWT}{dt}\right|_{t=14wks} = 9.72 \tag{16}$$

$$\left.\frac{dLean\%}{dWT}\right|_{WT:1\rightarrow 2} = -1.41\% \tag{17}$$

$$\left.\frac{dLean\%}{dWT}\right|_{WT:2\rightarrow 3} = -1.38\% \tag{18}$$

$$\left.\frac{dLean\%}{dWT}\right|_{WT:3\rightarrow 4} = -1.35\% \tag{19}$$

Hog distributions similar to those generated for 13, 14, and 15 weeks on feed were calculated for the intervals: 13 to 14 weeks on feed, 13 to 15 weeks on feed, and for 14 to 15 weeks on feed. It was assumed that any hogs in the heaviest and least lean categories would be sold. The resulting distributions of the remaining hogs are given in Tables A6 through A8. Each table accounts for 100 percent of the remaining hogs following removal of the heaviest and least lean hogs. As the tables illustrate, it takes about two weeks for a hog to grow into another type. This comes as a by-product from the construction of the weight and leanness ranges used in this research. Had the ranges been narrower it would conceivably take less time for the hogs to grow into different categories.

Table A6. Hog Type Distribution Transition From 13 to 14 Weeks on Feed ($G_{13|14}$)

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.00%	0.00%	0.00%
225 to 250	0.00%	9.61%	4.43%
250 to 275	0.00%	59.34%	5.31%
275 to 300	0.00%	20.40%	0.92%

Table A7. Hog Type Distribution Transition From 13 to 15 Weeks on Feed ($G_{13|15}$)

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.00%	0.00%	0.00%
225 to 250	0.00%	0.00%	0.00%
250 to 275	12.21%	5.63%	0.00%
275 to 300	75.41%	6.75%	0.00%

Table A8. Hog Type Distribution Transition From 14 to 15 Weeks on Feed ($G_{14|15}$)

	Leanness Categories		
Weight Categories	44% to 48%	48% to 52%	52% to 56%
220 to 225	0.00%	0.00%	0.00%
225 to 250	0.00%	35.03%	4.54%
250 to 275	0.00%	52.39%	3.17%
275 to 300	0.00%	4.84%	0.03%

Live Hog Marketing and Primal Sales

Each of the system models uses different decision-making processes to determine the quantities of live hogs and primal cuts sold in a period. In the spot market system, the production sector decides when and which hog types, differentiated on weight and leanness, to sell to the packer, and the packer passively accepts what is delivered and subsequently decides what the level of primal sales/storage will be. The contract system model shifts the live hog marketing decision to the packer through a buyer's call option present in the contract. The packer simultaneously decides which hogs to buy and the level of primal sales/storage. Here the packer is maximizing returns from primal sales less live hog expenditures by choosing the quantity of primal cuts to sell/store and live hogs to buy. In the vertical integration model where there are no live hog sales transactions occurring, rather only transfers from the growing unit to the slaughter unit, the packer optimally chooses primal sales and then selects, or "picks", the most efficient way to get those primal cuts from the pigs available.

Hog Marketing and Primal Sales in the Spot Market System Model

In the spot market system model the producer maximizes returns over variable costs to finishing feeder pigs to determine what hog types will be marketed. The hogs available to market are those feeder pigs that entered the finishing barns 13, 14, and 15 weeks prior and that have not been sold yet. This gives the producer a 3-week marketing horizon. When making the determination of whether to market today, next week, or the following week, the producer uses their expectation of the live hog price as determined by forecasting with the input-output state-space model. The packer then maximizes returns over variable costs to slaughtering hogs and processing pork into primal cuts commonly referred to as Green Pack. The packer decides what quantity of primal cuts to sell or store in a period and faces a storage capacity constraint. Additionally, the producer is forced to market hogs that are in the heaviest weight (10,11,12) and lowest leanness (1,4,7,10) categories.

Spot Market System Hog Marketing

The producer's marketing decision is set up as a binary choice problem where the choice is when to market a specific hog type. The revenue from marketing live hogs is given in equation 20 where $P_{i,t}^{LH}$ is the current period live hog price net of any premiums and discounts for hog type *i*. $E\left(P_{i,t+1}^{LH}\right)$ and $E\left(P_{i,t+2}^{LH}\right)$ are the state-space model live hog price forecasts for one and two periods ahead, respectively

$$REV_{PROD}^{SM} = P_{i,t}^{LH}\left\{FPP_{t-13}^{SM}G_{13}x_{i,13} + FPP_{t-14}^{SM}G_{14}x_{i,14} + FPP_{t-15}^{SM}G_{15}x_{i,15}\right\}$$

$$+ \mathrm{E}\left(P_{i,t+1}^{LH}\right)\left\{\left(FPP_{t-13|14}^{SM} - Sales_{t-1,13}^{LH}\right)G_{13|14}x_{i,23} + \left(FPP_{t-14|15}^{SM} - Sales_{t-1,14}^{LH}\right)G_{14|15}x_{i,24}\right\}$$

$$+ \mathrm{E}\left(P_{i,t+2}^{LH}\right)\left\{\left(FPP_{t-13|15}^{SM} - Sales_{t-2,13}^{LH}\right)G_{13|15}x_{i,33}\right\} \qquad (20)$$

FPP_{t-n}^{SM} are the feeder pigs placed in finisher barns in the spot market system model *n* weeks prior, where n = 13, 14, and 15. $G_{13}, G_{14}, G_{15}, G_{13|14}, G_{14|15}, \text{and } G_{13|15}$ are the growth transition matrices calculated in the previous section and describe how hogs in finisher barns grow over time with respect to weight and leanness. $Sales_{t-n,i}^{LH}$ reflect hogs of type *i* that have been sold previously. The zero/one binary choice variables corresponding to sale of hogs that have been on feed for 13, 14, and 15 weeks in the current period are denoted $x_{i,13}, x_{i,14}, \text{and } x_{i,15}$ respectively. The choice variables corresponding to the decision to keep current period hogs that have been on feed for 13 and 14 weeks in the finishers until the next marketing period are $x_{i,23}$ and $x_{i,24}$. The choice variables corresponding to holding the current period hogs that have been on feed 13 weeks for two additional marketing periods is $x_{i,33}$.

The costs associated with sales in a period are given in equation 21 and account for the feeder pig purchase price and the costs to feed a hog from a 50 pound feeder pig to a market weight hog of the desired weight. The costs of feed were taken from Lawrence and Vontalge and are given in Table A9.

Table A9. Average Per Pound Feed Costs to Finishing Feeder Pigs

Weight Category Fed To	Cost per Pound of Gain
200 to 225	\$0.110
225 to 250	\$0.115
250 to 275	\$0.120
275 to 300	\$0.130

$$COST_{PROD}^{SM} = x_{i,13}FPP_{t-13}^{SM}\left(P_{t-13}^{FP} + FC_i\right) + x_{i,14}FPP_{t-14}^{SM}\left(P_{t-14}^{FP} + FC_i\right)$$

$$+ x_{i,15}FPP_{t-15}^{SM}\left(P_{t-15}^{FP} + FC_i\right) \qquad (21)$$

The variable costs component in the producer's objective function represent costs associated with the current period's sale of feeder pigs placed in finisher barns 13, 14, and 15 weeks ago. $x_{i,13}, x_{i,14}, \text{and } x_{i,15}$ are choice variables as defined above and $FPP_{t-13}^{SM}, FPP_{t-14}^{SM}, \text{and } FPP_{t-15}^{SM}$ are the feeder pigs placed in finisher barns 13, 14, and 15 weeks ago respectively. $P_{t-13}^{FP}, P_{t-14}^{FP}, \text{and } P_{t-15}^{FP}$ are the prices paid for those feeder pigs placed respectively, and FC_i are the costs to feed a feeder pig to weight category *i*. The producer maximizes $\Pi^{SM} = REV_{PROD}^{SM} - COST_{PROD}^{SM}$ by choosing $x_{i,13}, x_{i,14}, \text{and } x_{i,15}$ to determine which hog types will be marketed to the packer. Following the producer's decision a flow of live hogs differentiated by their weight and leanness are sold to the packer. In the spot market the packer accepts all the hogs delivered in any period and prices them according to the Input-Output Price model.

Spot Market System Primal Sales

The packer in the spot market system is delivered a predetermined quantity of hog types from the producer's decision. The packer then solves a sell/store decision to determine the level of primal cut sales and storage in period *t*. The packer's problem is given in equations (22) through (25). The packer's objective is to maximize returns over variable costs from processing live hogs into primal cuts and is given by equation (22), where $Q_{p,t}^{PC}$ is the quantity of the *p* primal cuts sold in period *t* and $P_{p,t}^{PC}$ are their respective prices.

$$ROVC_{PACK}^{SM} = \sum_p Q_{p,t}^{PC} P_{p,t}^{PC} + \sum_p QS_{p,t}^{PC} Max\{E(P_{p,t+1}^{PC}), E(P_{p,t+2}^{PC})\} \quad (22)$$

$$- \sum_i Q_{i,t}^{LH} \left(P_{i,t}^{LH} + PC_i\right)$$

$$Q_{i,t}^{LH} = x_{i,13}^* FPP_{t-13}^{SM} + x_{i,14}^* FPP_{t-14}^{SM} + x_{i,15}^* FPP_{t-15}^{SM} \quad (23)$$

$$Q_{p,t}^{PC} + QS_{p,t}^{PC} \le \sum_i Q_{i,t}^{LH} Tr_{i,p} + QS_{p,t-1}^{PC} \quad (24)$$

$$\sum_p QS_{p,t}^{PC} \le \overline{QS^{PC}} \quad (25)$$

$QS_{p,t}^{PC}$ are the quantities of primal cut p stored from period t to period $(t+1)$. The packer uses a two period horizon over which to determine if primal prices will be more favorable than current period primal prices by forming price expectations from the state-space input-output price model represented by $E(P_{p,t+1}^{PC})$, and $E(P_{p,t+2}^{PC})$. $Q_{i,t}^{LH}$ are the quantities of each i^{th} hog type delivered from the producer model and $P_{i,t}^{LH}$ are their prices net of any premiums and discounts. PC_i are per head variable costs to slaughter a hog and were taken from Hayenga to be approximately $0.08 per pound of live pork entering the plant.

There were three constraints put on the packer's objective function to ensure that they were indeed buying all the hogs delivered to them (23), not selling more primal cuts than they were able to process in the current period plus any inventory (24), and that capacity of their cold storage facility was not exceeded (25). All variables are as previously defined and optimal values from the producer's marketing decision are denoted with an asterisk. In equation (24) $Tr_{i,p}$ is the transformation matrix, or cutout table, of a live hog into primal cuts. The cutout table used was from the Department of Animal Science at Purdue University and is provided in Appendix C. $\overline{QS^{PC}}$ is the storage capacity imposed on the packer. The packer was permitted to store approximately 20 percent of their average weekly slaughter, which was 3,629,472[4] pounds of primal cuts. This was the average percent of slaughter in cold storage from March 1995 to March 2001 as reported in the USDA's Cold Storage Report. The outputs from the packer's primal cut sales model are levels of primal cut sales, and storage and the shadow prices from equation (23) give the packer's marginal value for an additional hog of each type i.

Contract System Hog Marketing and Primal Sales

In the contract coordinated system the packer makes all the decisions and calls for individual hog types as needed from the contracts they hold. In the contract system model the packer uses two stages to determine optimal live hog marketings and primal sales. In the first stage the packer solves for optimal live hog marketings using expected primal cut prices. In the second stage the packers treats live hog inputs as given and primal cut prices are known and they solve for optimal primal cut sales/storage.

[4] 3,629,472 lbs primal cuts = 19.64% * 13,200 hogs/day * 6 days * 80% Cap Util * 250 avg lbs/hog

In the first stage the packer solves the following problem by choosing primal cut sales ($Q_{p,t}^{PC}$), primal cut storage ($QS_{p,t}^{PC}$), and live hog marketing's (x_i's) to maximize $ROVC_{PACK}^{SM}$ in equation (26). As in the spot market system the packer has a 3-week window over which to market all hogs placed in finisher barns 15 weeks prior. The packer makes hog marketing decisions based on expected primal cut prices, $E\left(P_{i,t}^{PC}\right)$, rather than actual prices. The variable B is the bailment, or fixed per head payment, that the packer makes to the producer upon marketing. B was initially chosen to be \$5.00 following documentation by Martin (1999a) and Lawrence.

$$ROVC_{PACK}^{CC} = \sum_p Q_{p,t}^{PC} E\left(P_{p,t}^{PC}\right) + \sum_p QS_{p,t}^{PC} Max\left\{E\left(P_{p,t+1}^{PC}\right), E\left(P_{p,t+2}^{PC}\right)\right\} \tag{26}$$

$$-\sum_i \left(P_{i,t}^{LH} + B\right)\left(FPP_{t-13}^{CC} x_{i,13} + FPP_{t-14}^{CC} x_{i,14} + FPP_{t-15}^{CC} x_{i,15}\right)$$

$$-\sum_i E\left(P_{i,t+1}^{LH} + B\right)\left(FPP_{t-13|14}^{CC} x_{i,23} + FPP_{t-14|15}^{CC} x_{i,24}\right)$$

$$-\sum_i E\left(P_{i,t+2}^{LH} + B\right)\left(FPP_{t-13|15}^{CC} x_{i,33}\right)$$

$$Q_{p,t}^{PC} + QS_{p,t}^{PC} \le \sum_i \left(x_{i,13} FPP_{t-13}^{CC} + x_{i,14} FPP_{t-14}^{CC} + x_{i,15} FPP_{t-15}^{CC}\right) Tr_{i,p} + QS_{p,t-1}^{PC} \tag{27}$$

$$\sum_p QS_{p,t}^{PC} \le \overline{QS^{PC}} \tag{28}$$

In the second stage the packer solves a primal cut sell/store decision with current period primal cut prices known and live hog deliveries fixed. The second stage of the packer's problem in the contract system model is given in equations (29) through (32). The second stage problem is similar to the packer's sell/store decision in the spot market system with the addition of a live hog deliveries constraint (30). In the contract system model, FPP come from the estimated contract system feeder pig equation (FPP^{CC}).

$$\sum_p Q_{p,t}^{PC} P_{p,t}^{PC} + \sum_p QS_{p,t}^{PC} Max\left\{E\left(P_{p,t+1}^{PC}\right), E\left(P_{p,t+2}^{PC}\right)\right\} - \sum_i Q_{i,t}^{LH}\left(P_{i,t}^{LH} + PC_i\right) \tag{29}$$

$$Q_{i,t}^{LH} = x_{i,13}^{*} FPP_{t-13}^{CC} + x_{i,14}^{*} FPP_{t-14}^{CC} + x_{i,15}^{*} FPP_{t-15}^{CC} \tag{30}$$

$$Q_{p,t}^{PC} + QS_{p,t}^{PC} \le \sum_i Q_{i,t}^{LH} Tr_{i,p} + QS_{p,t-1}^{PC} \tag{31}$$

$$\sum_p QS_{p,t}^{PC} \le \overline{QS^{PC}} \tag{32}$$

Vertical Integration System Hog Marketing and Primal Sales

In a vertically integrated system, the packer does not procure live hogs from any market, but rather produces all needed inputs from their own finishing facilities. The packer in the vertical integration system faces a two-stage problem like the packer in the contract system. The key difference in the vertical integration system is that the associated input price is the feeder pig price plus the cost of feeding hog type i to market weight. In the first stage, the packer maximizes returns over variable cost from slaughter and processing live hogs subject to the same set of constraints as in the two previous system models. Also like the two previous system models the packer is making live hog input decisions based on expected primal prices. The vertical integration system packer's first stage problem is specified in equations (33) through (35).

$$ROVC_{PACK}^{VI} = \sum_{p} Q_{p,t}^{PC} E\left(P_{p,t}^{PC}\right) + \sum_{p} QS_{p,t}^{PC} Max\left\{E\left(P_{p,t+1}^{PC}\right), E\left(P_{p,t+2}^{PC}\right)\right\} \tag{33}$$

$$-\left(P_{t-13}^{FP} + FC_i\right) FPP_{t-13}^{VI} x_{i,13}$$

$$-\left(P_{t-14}^{FP} + FC_i\right) FPP_{t-14}^{VI} x_{i,14}$$

$$-\left(P_{t-14}^{FP} + FC_i\right) FPP_{t-15}^{VI} x_{i,15}$$

$$Q_{p,t}^{PC} + QS_{p,t}^{PC} \le \sum_{i} \left(x_{i,13} FPP_{t-13}^{CC} + x_{i,14} FPP_{t-14}^{CC} + x_{i,15} FPP_{t-15}^{CC}\right) Tr_{i,p} + QS_{p,t-1}^{PC} \tag{34}$$

$$\sum_{p} QS_{p,t}^{PC} \le \overline{QS^{PC}} \tag{35}$$

The second stage problem for the vertical integration system packer now becomes similar to the contract system packer's second stage problem. The differences arise in the resource constraints on live hog inputs available to be slaughtered and processed. The second stage problem for the vertical integration system packer is specified in equations (36) through (39).

$$\sum_{p} Q_{p,t}^{PC} P_{p,t}^{PC} + \sum_{p} QS_{p,t}^{PC} Max\left\{E\left(P_{p,t+1}^{PC}\right), E\left(P_{p,t+1}^{PC}\right)\right\} - \sum_{i} Q_{i,t}^{LH}\left(P_{i,t}^{LH} + PC_i\right) \tag{36}$$

$$Q_{i,t}^{LH} = x_{i,13}^{*} FPP_{t-13}^{VI} + x_{i,14}^{*} FPP_{t-14}^{VI} + x_{i,15}^{*} FPP_{t-15}^{VI} \tag{37}$$

$$Q_{p,t}^{PC} + QS_{p,t}^{PC} \le \sum_{i} Q_{i,t}^{LH} Tr_{i,p} + QS_{p,t-1}^{PC} \tag{38}$$

$$QS_{p,t}^{PC} \le \overline{QS^{PC}} \tag{39}$$

All of the live hog marketing and primal cut sale/storage models provide optimal physical flows of live hogs and primal cuts. These physical pork flows are transformed into financial flows of dollars through their respective input and output markets. The following section details the model used for the input and output market prices.

Input and Output Market Price Model

The market prices for feeder pigs, live hogs, and primal cuts were modeled as a multivariate stochastic process. The use of an exogenous model to price production outputs/packing inputs along with packing outputs prevents any form of non-competitive behavior by either the producers or the packer. The model used for the input/output prices was a state-space time series model as specified in equations (4) and (5). There were eight price series modeled jointly in a multivariate system consisting of: feeder pigs, live hogs, hams, bellies, loins, ribs, butts, and picnics.

State Space Estimation of the Input and Output Market Prices

The results from the estimation of the model are summarized in Table A10 and Figures A5 through A12 are plots of the actual data, estimates, and the errors for each price series. All models fit very well, with squared correlations (analogous to R^2) ranging from 0.83 to 0.98. The plots of the actual and estimated points are more informative of the model's fit. The estimated series track all the actual series extremely well, and up-turns and down-turns in the actual data are also matched by the estimated series.

Table A10. State Space Model Results for the Input Output Market

Series	*Mean*	*RMSE*	*Squared Correlations*[a]
Feeder Pig[b]	41.27	1.5536	0.9818
Hog[c]	0.4420	0.0202	0.9731
Ham	0.4654	0.0302	0.8521
Loin	0.8154	0.0454	0.8820
Belly	0.5416	0.0562	0.8916
Picnic	0.3171	0.0118	0.9672
Rib	0.9251	0.0409	0.9416
Butt	0.5516	0.0498	0.8332

[a]Squared correlations between actual and predicted values are used as an analog to R^2
[b]Feeder pig price series values are in $ per head
[c]All other price series are $ per pound

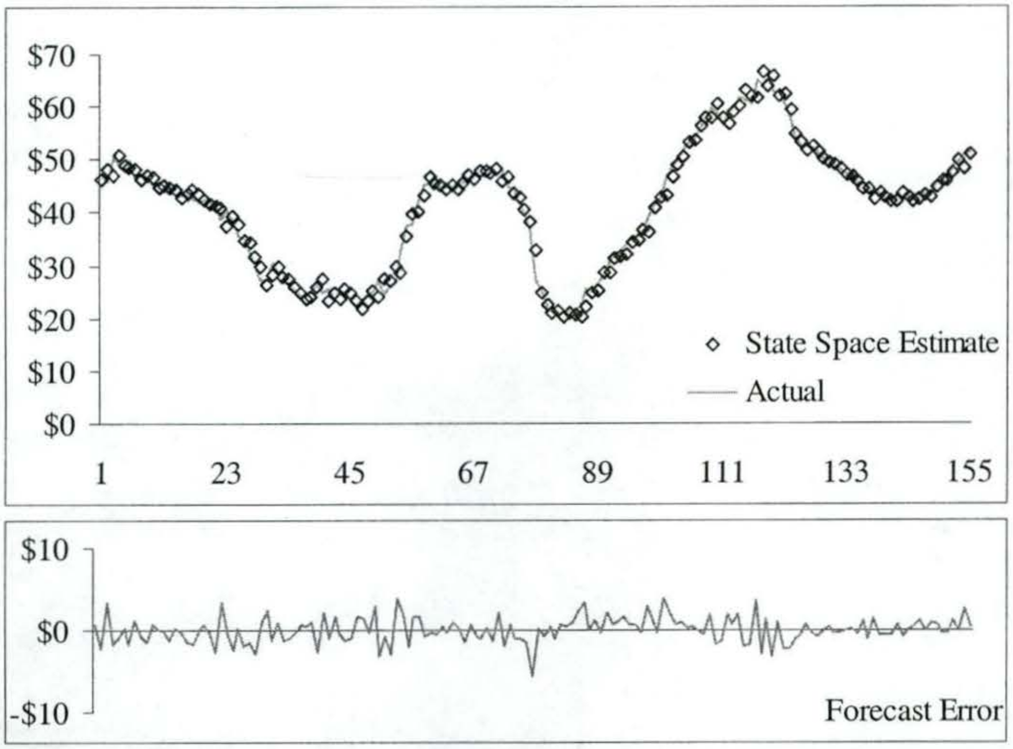

Figure A5. State Space Estimation of Feeder Pig Prices: Actual, Forecast, and Errors

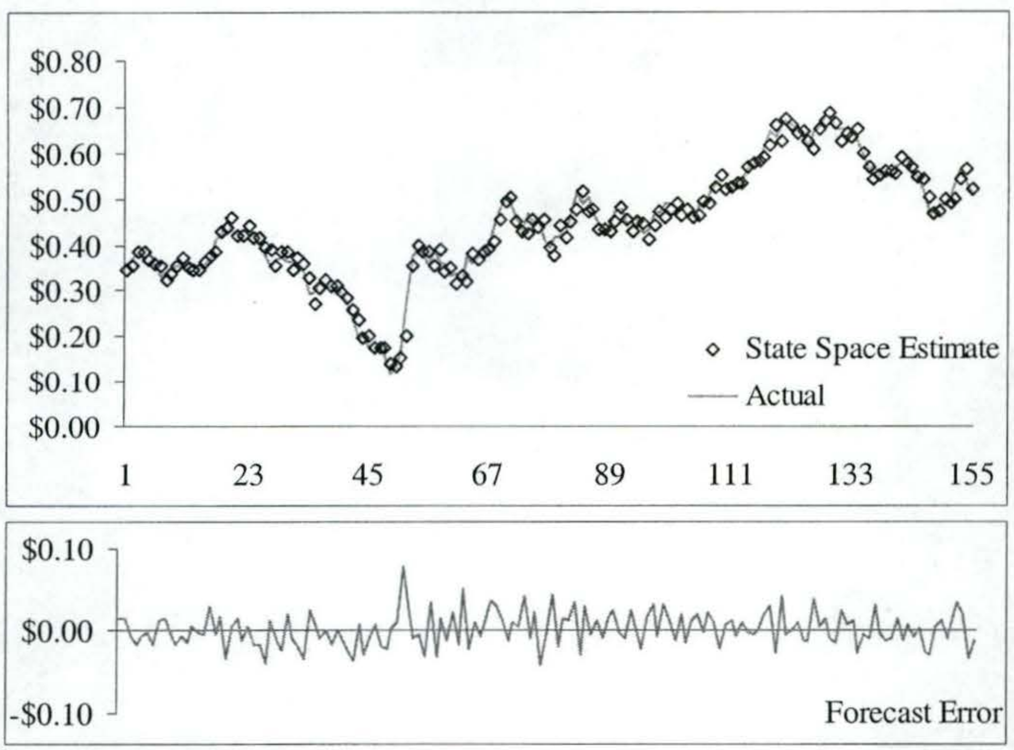

Figure A6. State Space Estimation of Cash Hog Prices: Actual, Forecast, and Errors

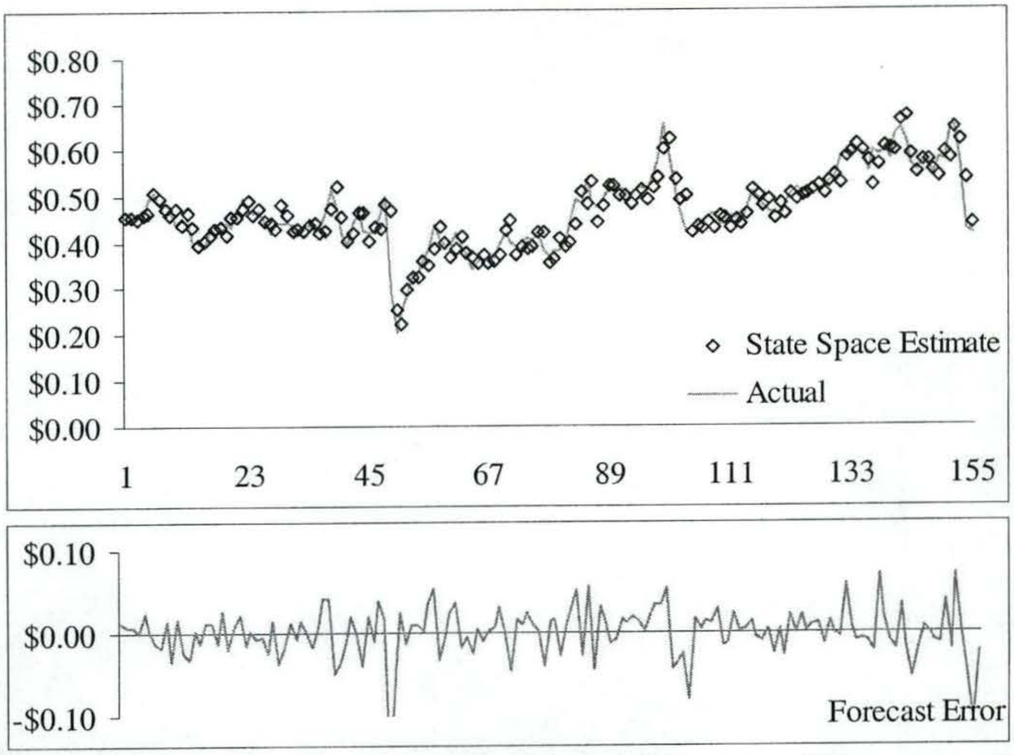

Figure A7. State Space Estimation of Ham Prices: Actual, Forecast, and Errors

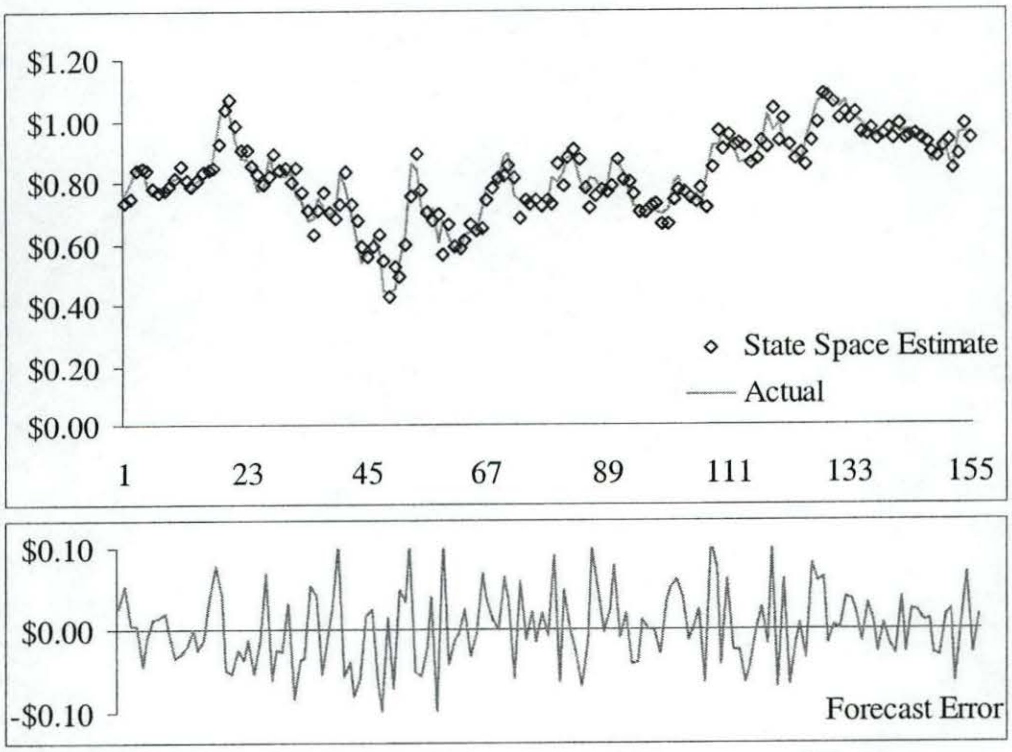

Figure A8. State Space Estimation of Loin Prices: Actual, Forecast, and Errors

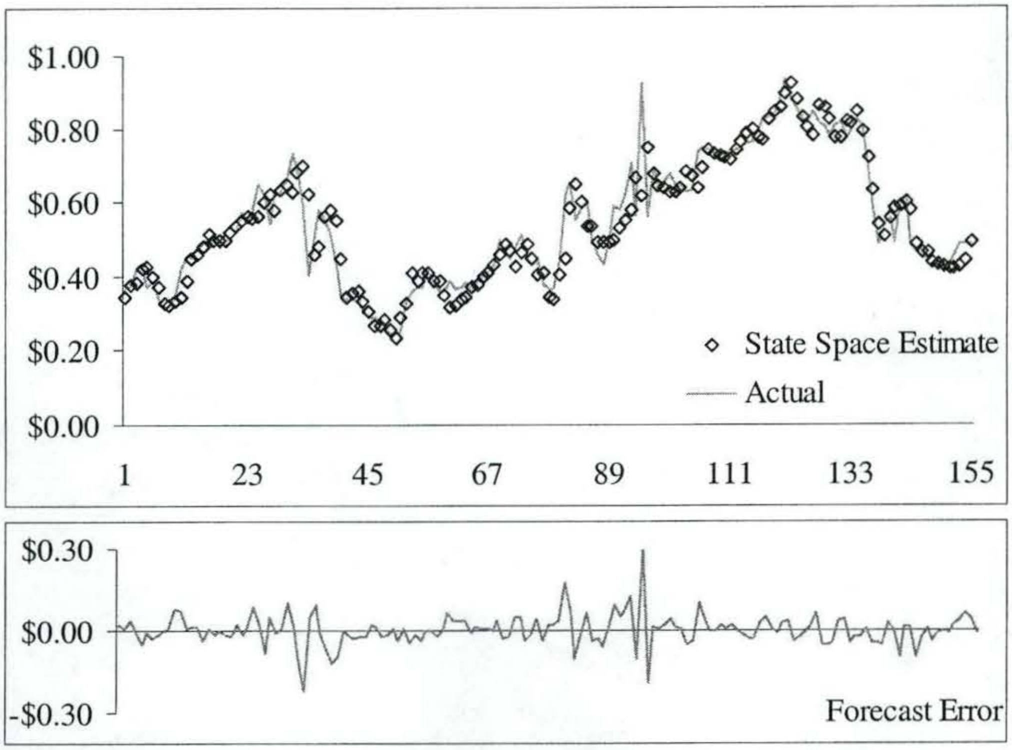

Figure A9. State Space Estimation of Belly Prices: Actual, Forecast, and Errors

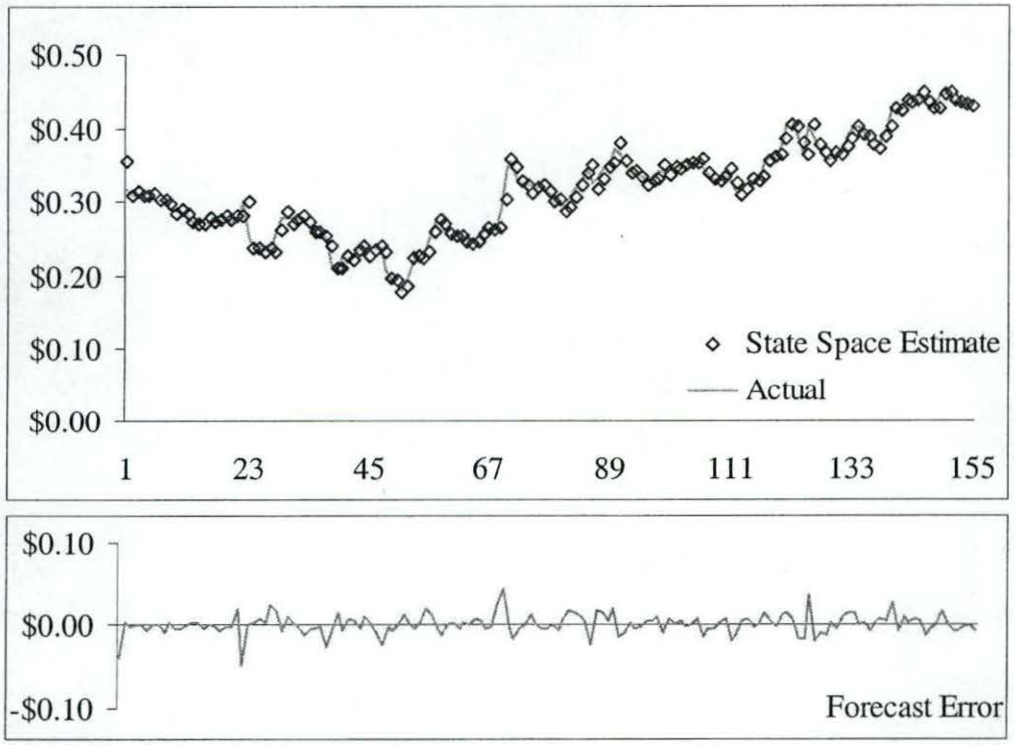

Figure A10. State Space Estimation of Picnic Prices: Actual, Forecast, and Errors

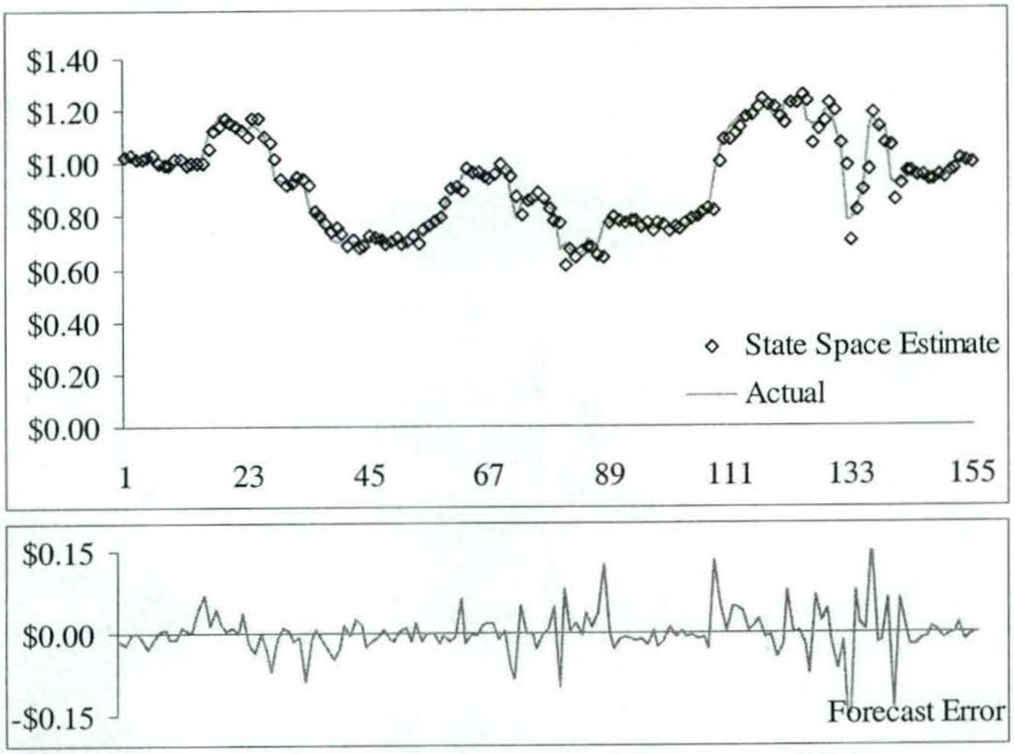

Figure A11. State Space Estimation of Rib Prices: Actual, Forecast, and Errors

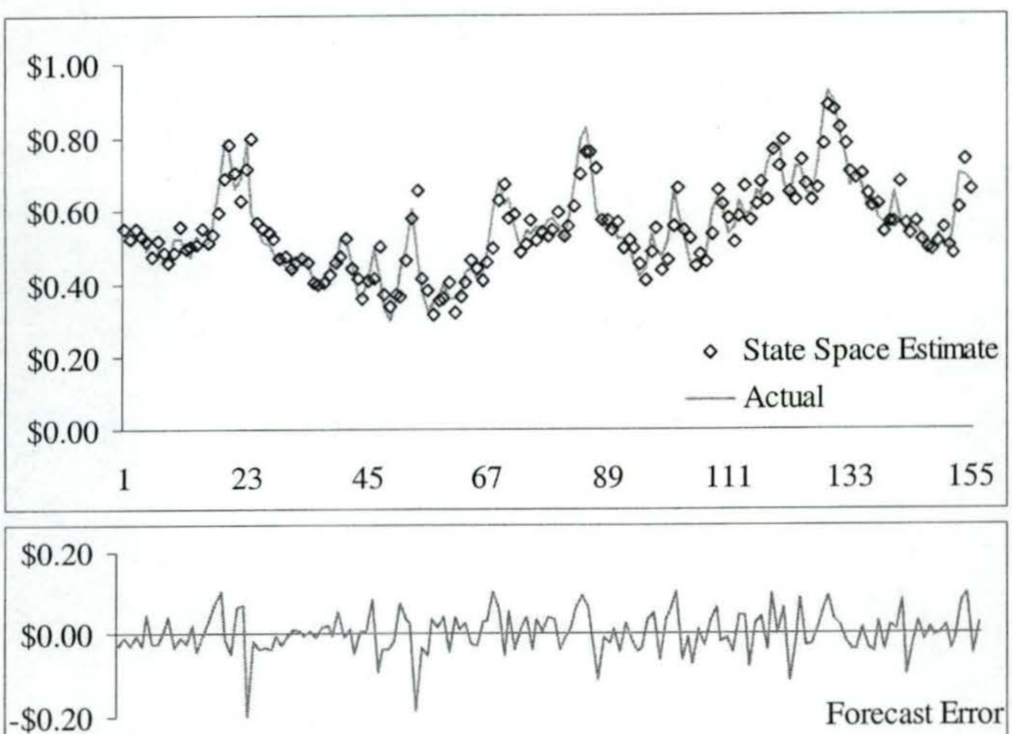

Figure A12. State Space Estimation of Rib Prices: Actual, Forecast, and Errors

Simulating Input and Output Markets

Simulating the input and output price markets was conducted similar to the simulation of feeder pig placement. Simulation was performed by drawing correlated normal deviates and using the above estimated state-space model.

<u>Live Hog Pricing</u>

In all marketing models the net price for live hogs has two components, base price and P&D schedule. The base price comes from the state-space input and output market price model and is for a 225 to 250 pound 48% to 52% lean hog (category 5). This is the base hog and all other hogs are priced in reference to this hog. The P&D schedule is derived from the packer's primal sale problem. The shadow prices from the live hog constraint (equations (23), (30), and (37) for each system model respectively) are used to construct future periods P&D schedules. The shadow prices difference from the base hog give the packer's marginal value to each additional hog of type *i* relative to the base hog.

In all of the system models the P&D schedule was defined as the average of the previous years shadow price differences over two six month ranges, January to June and July to December. For example, if t were any week from January through June, $P\&D_i = \frac{1}{26}\sum_{Jan}^{June}\left(\lambda_{i,n} - \lambda_{5,n}\right)$, where the sum is over all weeks in the interval of January to June of the previous year. A similar rule was used for the interval of July to December. This method forced the packer to value hogs at their true marginal values as determined by primal sales. Previous year six-month averages were chosen to capture seasonal differences in primal cut values while at the same time not allowing the P&D schedules to change too frequently. This frequency choice was fairly robust as shown in Poray and Gray. In addition, personal interactions with producers indicated a preference for grids that changed no sooner than six months intervals as they questioned then motives behind more frequently changing P&D schedules. To have P&D schedules for simulation purposes, an additional year was simulated prior to the two-year period over which performance was analyzed.

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