A System Dynamics Model of Information Feedback and Activity Coordination in an Agricultural Value Chain[1]

L. Martin Cloutier

Agricultural Education & Consulting
3 College Park Court
Savoy, IL 61874
e-mail: lmc@centrec.com

Steven T. Sonka

Soybean Industry Chair in Agricultural Strategy
National Soybean Research Laboratory
University of Illinois at Urbana-Champaign
1101 W. Peabody Drive,
Urbana, IL 61801
e-mail: s-sonka@uiuc.edu

Abstract

This paper summarizes a research effort that considered the effect of alternative coordination mechanisms within an agricultural value chain. The system dynamics model presented in this work focuses on the modeling of endogenous information feedback at the boundary between hog production and packing activities. The value chain subsectors of the model are specified to study dynamic behavior assuming various degree of information feedback from the business environment. The paper includes detailed influence diagrams of alternative coordination mechanisms and discusses some simulation results.

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1. INTRODUCTION

Competitive pressures often require the redesign of organizations (also called 'unbundling' or 'commodification' of functions, or vertical 'disintegration') to permit more effective coordination across highly specialized business functions delivering more value to end-users and removing costs from the system (Poirier and Reiter, 1996). In today's business environment closer firm relationships (handshake agreements, contracts, networks, alliances, and even networks of alliances (Gomes-Casseres, 1996)) make possible the effective coordination of dependencies across activities in the achievement of business goals in alternative value chain designs. Examples abound illustrating how precise requirements to resource access and the push for cost reduction in the delivery of higher value product functionality to end-users have made the boundaries of markets, industries, and firms increasingly difficult to delineate (Cloutier *et al*., 1997a). In this context, products also have become more difficult to separate from services as information-based transactions between suppliers and customers are increasing across one or several linkages in the value chain (Glazer, 1993). Perhaps less discussed, these changes in the business environment that affect the conduct of transactions, although more commonly addressed in the banking and automobile industries, have impacted the food and agribusiness sector as well.

For example, during the past decade a growing market for U.S. pork (currently more than $ 30 billion) has led hog production to become more coordinated with downstream activities. Hog producers, as suppliers of raw material to packers, receive economic incentives to become food ingredient suppliers. Conformance quality, an essential component that requires increased information transmission and the implementation of effective coordination mechanisms in the management of activities within the 'pork chain', is key to economic survival and end-user value creation in that sector. However, industry participants are reminded of the limitations of traditional market-based coordination mechanisms employed in the production of commodities: "market signals can be effective, but they tend to be slow and blunt" (Lawrence, 1997:220). The satisfaction of end-user needs that are increasingly function and convenience-oriented passes through the identification of dependencies and the design and implementation of innovative coordination mechanisms. Indeed, research findings indicate that operation-driven pricing coordination mechanisms are not sufficient for industry alignment because they do not translate into quantitative information and executable knowledge for hog producers and pork packers (Miranda, 1997). The role of transactional innovations, such as a component price mechanism, is to remove uncertainty about the potential extraction value of a particular hog carcass (or any other agricultural product) at a particular point in time in the conduct of operations. However, the component price mechanism does not remove the temporal uncertainty about production delays, producer and packer reaction time adjustment to price changes, and other essential information that is needed for effective decision making within a complex business system.

The dynamic hypothesis examined in this work posits that information scarcity is often characterized by longer price transmission delays within the system of hog production and packing activities. The scarcity of information typical of price incentive mechanisms in production agriculture asynchronously penalizes both producers and downstream industry participants because it fragments the coordination of functions and it limits the endogenous allocation of resources that creates value within the system. This outcome results in a major impediment to long-run organizational improvement because, short-run fluctuations create economic instability that impedes the management of information necessary to adjust supply with demand conformance requirements of raw agricultural material of downstream processing stages.

The general objective of this summary paper is to outline the development of a synthesis model to learn more about the economic role of information feedback in the strategic management of physical and financial stock and flow interactions within and across business activities in hog production and pork packing. Conceptualized with the input of industry participants, the hog production and packing value chain model captures physical, economic and conformance feedback interactions in the execution of activities over time. The research effort makes two important contributions. First, it focuses on endogenous information feedback at the interface between production and packing activities within a value chain. Second, the value chain subsectors receive market feedback from the business environment subsector.

This research effort explores information feedback as a source of economic value creation within and across business activities among organizations interacting within a prototypical pork value chain. The conceptual role of information feedback is to reduce the temporal uncertainty and time delays in physical and economic stock and flow adjustments created by information scarcity within supply chains.

The problem addressed in this study is summarized as follows. Information scarcity within a system results in (a) misalignment in the coordination mechanism for the production and delivery of hog component characteristics in the short-run; and (b) the non-availability of resources required to enhance organizational design of function coordination in the long-run. Information scarcity limits a system's ability to create economic value through time. Understanding the mechanisms by which information feedback creates economic value presents an intriguing research opportunity within the context of an increasingly dynamic business environment.

2. MODELING APPROACH

The development of the System Dynamics Pork Coordination Model (SDPCM) follows a modeling approach consistent with the structure of producer and packer relationships. Many theoretical concepts employed in this research effort are based on economic theory, dynamic strategic management theory, and operations research methods. These concepts were chosen because of their fit with the modeling of a dynamic system whose structure is to reproduce as closely as possible observed patterns of economic behavior. These concepts define broadly the principles that underlie the system dynamics approach (Forrester, 1994). The uniqueness of the approach taken here to model producer and packer interfaces does not come from one particular concept but from combining several concepts into a synthesis.

Consistent with previous work in system dynamics the perspective of this research effort is that dynamic behavior can be explained from feedback structures endogenous to the system (Coyle, 1979; Forrester, 1994; Lyneis, 1980; Senge, 1990). This implies that economic change is a result of interactions among components and of decision rules embedded within the system. Economic questions of interest often relate to change over time.

The market clearing mechanism specified in the model differs from the neoclassical perspective on supply and demand. Instead, the market clearing conditions depend on more realistic assumptions that account for observed production and delivery time delays. This is also the feedback structure that drives the buildup of inventories. These shortages and surpluses are underlying influences of price changes in markets (Forrester, 1982; Lyneis, 1980). In modeling business behavior that employs market price as a market clearing mechanism often more is learned by focusing our modeling efforts on structural components that create disequilibrium behavior.

Herbert Simon's (1959) 'bounded rationality' is a central concept in system dynamics modeling (Forrester, 1989; Lant, 1992; and Morecroft, 1985). System dynamics models try to capture the structure of decision feedback within systems. Decision-makers try their best and make rational decisions given the information and perception they have of a situation. The decision is intended to be rational. Bounded rationality relates to the difficulty of perceiving, for example, how decision responses to short-run signals match with long-run objectives. This assumption is important as it relates to the adjustments within the information feedback structures of the coordination mechanisms studied and simulated by the model.

3. DYNAMIC HYPOTHESIS OF INTERORGANIZATIONAL ACTIVITY COORDINATION

This section briefly outlines the influence diagram of the mechanisms for component price and information coordination developed within the larger context of the research project. Figure 1 shows the influence diagram of producer and packer interactions in the component price coordination mechanism. The packer procurement incentives influence producer conformance information (R3b). Similarly, carcass conformance feeds into the packer conformance information (R4b). This exchange of information has advantages. Producers can receive payment for producing and shipping hogs with specific characteristics. The packer can more properly align hog procurement incentives to reflect the economic extraction potential of hog carcasses with the downstream marketing of pork meat. Component price coordination mechanism rests on suppliers and the customer intraorganizational expectations of conformance. Operational information about conformance is not sufficient. The interorganizational strategy of activity coordination is fragmented because information scarcity about quantity, timing and duration does not inform the suppliers and the customer expectations of conformance. The component price coordination does not reduce quantity, timing, and duration uncertainty at the tactical level. It also does not reduce quantity, conformance, timing, and duration uncertainty at the strategic level.

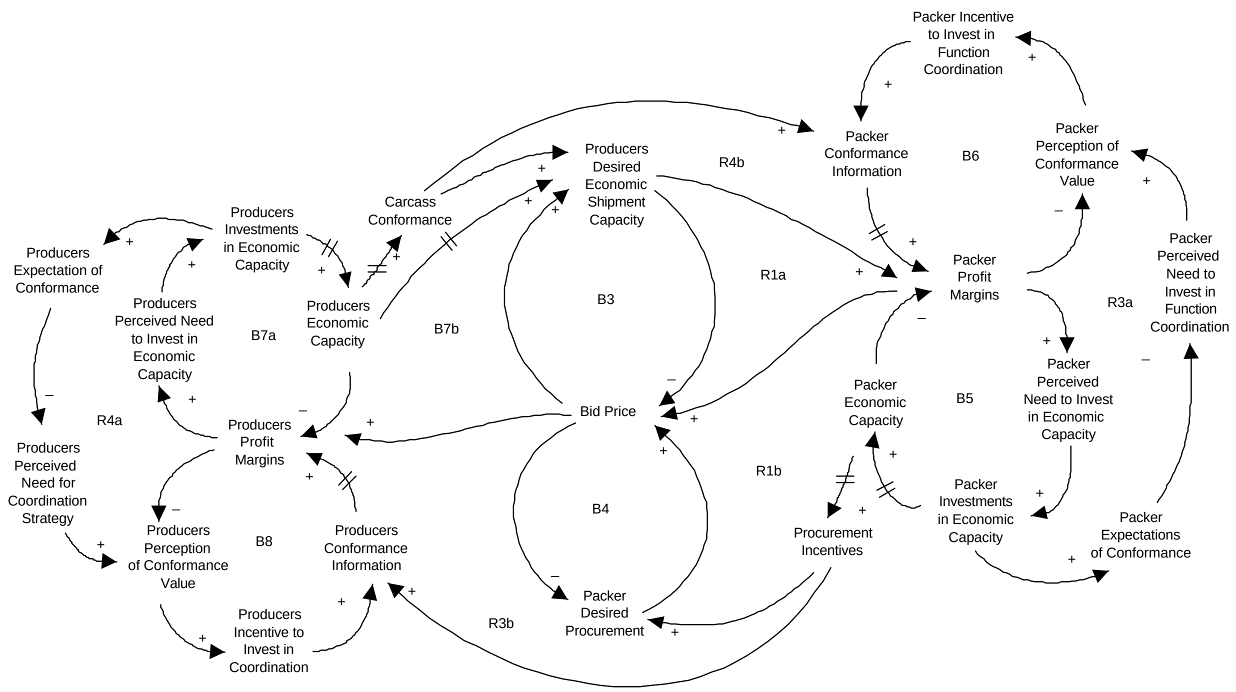

Figure 1 Influence Diagram of the Packer and Producers in the Component Price Coordination Mechanism

The information feedback coordination mechanism, shown in Figure 2, includes reinforcing loops that support the interorganizational strategy level interactions between producers and the packer. Information feedback requires a reinforcing loop between the packer's desired procurement and producers production pressures (R2a). This implies that producers receive procurement orders directly from the packer. This feedback loop has two important effects on the coordination structure. First, production quantities before delivery are no longer uncertain because information about the value of delivery at the operational level does not reduce temporal uncertainty. Second, and more importantly, loop R2b separates packer desired procurement from the bid price. Procurement incentives are realigned in a manner that makes it part of a reinforcing loop sequence (R1b, R2a, R2b, and R1a) that controls economic feedback on producers and the packer respective production and business pressures. This is accomplished by a direct alignment of the packer business decisions with procurement incentives, producers' capacity, and carcass conformance. The same sequence of reinforcing loops works for a greater feedback control of producer profit margins. These reinforcing loops make possible better control of the quantity, timing, and duration of desired economic shipments and procurement capacities. Available information about expectations of conformance (R5 and R6) makes possible more effective production and procurement across several carcass characteristics.

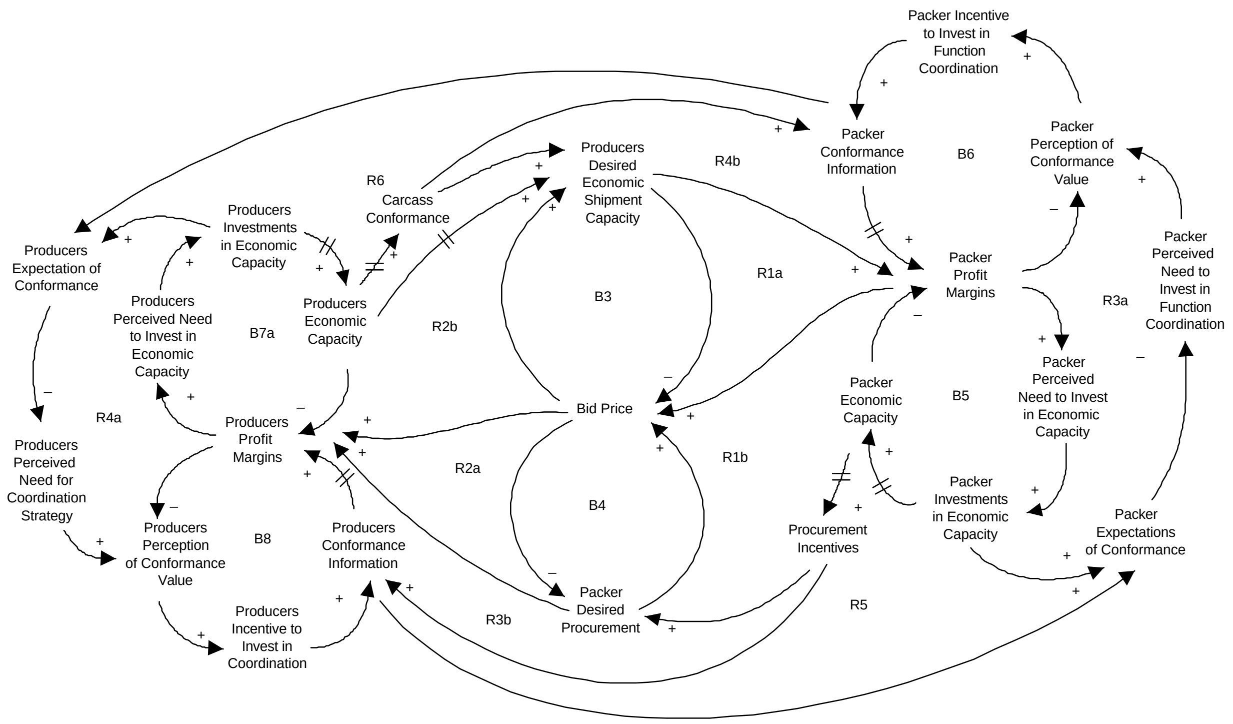

Figure 2. Influence Diagram of the Producers and Packer Information Feedback Coordination Mechanism

4. PURPOSE, SCOPE AND STRUCTURE OF THE SYSTEM DYNAMICS PORK COORDINATION MODEL

Figure 3 presents a conceptualization of the business environment and value chain at the activity level. This research concentrates on coordination issues at the boundary between hog production and pork packing. Overabstraction and conceptual ambiguity are hazards that can impair the effective development and modeling of problems relating to activities within and across organizations, and the proper characterization of influences from the business environment. To address conceptualization issues, the 'pork chain' specification in this work adapts the business environment terminology of the framework developed by Castrogiovanni (1991).

Starting at the center in Figure 3, the subenvironment includes activities that are represented within firms. The model represents three main activities managed by the packer - hog procurement, packing, and pork meat marketing. In addition to the packer's subenvironment, this model includes activities at the producer level that define the interface for transactions between hog delivery and hog procurement. The task environment following Osborn and Hunt (1974:233) includes "those organizations with which it must interact to grow and survive." As represented here, the task environment includes the firms that comprise the value chain. Castrogiovanni's (1991) 'macroenvironment,' is defined in this research as the 'business environment,' and includes entire industry level organizations and customer markets.

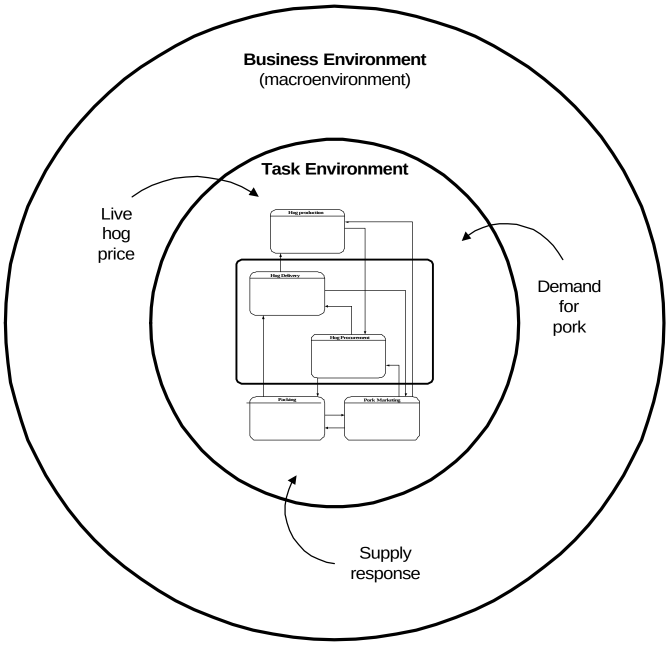

Figure 3 Business Environment and Value Chain Conceptualization

Although the market structure is changing and ensuing value chain designs and coordination mechanisms are varied, activities within a firm are still executed albeit organized differently. The recent focus in agricultural economic research has been to infer behavior based on exogenous factors of industrial economic archetypes for competitive markets relative to vertical or horizontal coordination. In particular, the research on interorganizational arrangements emphasizes descriptions in terms of economic forces that determine exogenous ‘causes’ for structural changes, including technological or transactional innovation. The methodological approach taken in this research emphasizes not the boundary between firms but rather interactions between activities within a firm as well as interaction with activities of other firms and influences with the larger business environment.

In the value chain definition extended by Porter (1994), the functionality of firms (or strategic business units) is broadened to include a set of activities at the subenvironment level. The representation of the coordination process at the activity level within a firm allows the detailed characterization of activities that yield endogenous responses to the market stimuli of the business environment. The shift in the unit of analysis from market structure to activity level is consistent with the modeling approach that seeks to identify endogenous forces within systems that determine dynamic behavior across linkages.

The model specification of the SDPCM is divided into two main components, the Business Environment Sector, and the Value Chain Sector. The business environment subsector is based on an amended and updated version of the Dynamic Commodity Model (Meadows, 1970). The Value Chain Sector comprises five subsectors. These subsectors are as follows: (1) Hog Production, (2) Hog Delivery and Procurement, (3) Packing, (4) Pork Meat Marketing, and (5) the respective production and packing Economic Subsector. The sectors include components with detailed decision rules that govern the behavior of each sector and of the overall model. The general structure of the overall value chain model is represented in Figure 4. Dark gray shaded areas in Figure 4 represent the activities included in the SDPCM in the value chain format. The lighter gray shaded area, represent supporting activities in the producers and packer infrastructure (the use of the coordination mechanism) and margins. Arrows connecting between sectors illustrate the notion that outcomes of decisions within one sector of the model have effects on other components of the model.

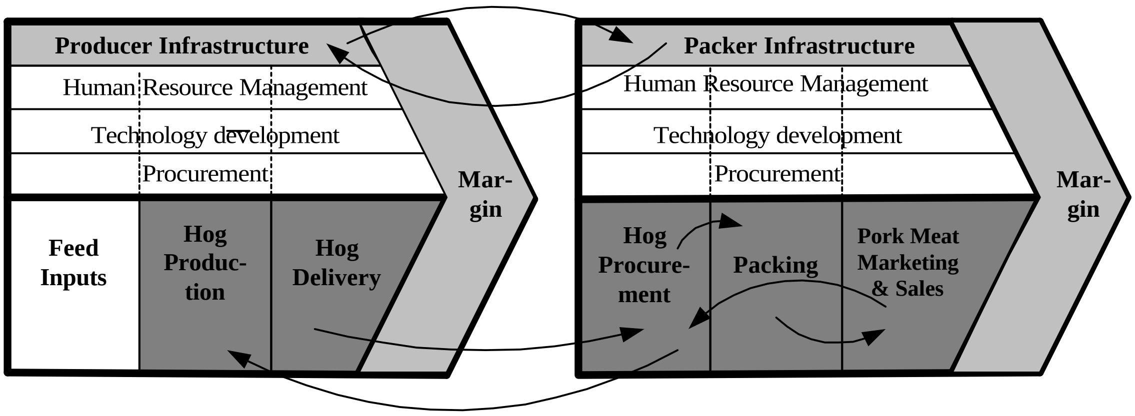

Figure 4 Value Chain Activities included in the SDPCM

Model boundary and scope details were determined in relation to their relevance to issues of information scarcity/feedback and of organizational improvement in pork value chains. Thus, high frequency random fluctuations of daily live hog and cutout market prices are not included in the model. Also, given the research objectives for which the SDPCM is developed, the baseline formulation relates to the long-run price behavior -- seasonal deterministic sources of variations have been omitted from the model. For example, although seasonal variations that relate to farrowing are typical in hog production, their effects are not captured by the baseline formulation of the model. Likewise, holidays have seasonal repercussions on the demand for pork meat cutouts and are not specified in the SDPCM. However, the model could be amended to capture seasonal influences. The dynamic business environment is used in this work to provide a pattern for the live hog price cycle and information feedback. The market interface of the endogenous business environment provides the hog production and pork packing coordination mechanisms with the necessary information linkages to avoid pitfalls associated with static partial budgeting approaches (Lyneis, 1980).

5. ANALYSIS OF INFORMATION TRANSMISSION ON VALUE CHAIN BEHAVIOR

An interesting application of the value chain sector is to show the importance of considering the role of the information feedback and the influence of time delays in the strategy implementation process. Figures 5 and 6 show simulation results under alternative specifications for a permanent five percent increase in demand for pork meat. Three alternative specifications were considered: (1) no market feedback (curves labeled 1 on all graphs); (2) the influence of market feedback using the price coordination mechanism (curves labeled 2 on all graphs); and (3) the influence of market feedback using the information feedback coordination mechanism (curves labeled 3 on all graphs). The results shown in Figures 5 and 6 examine the behavior over time of hog delivery, hog procurement, production and packing margins, production expansion, and chain speed efficiency. The production expansion and chain speed efficiency are ratios defined as follows:

- **Production expansion.** Measures the production throughput volume in each period normalized by its level at the start of the simulation. This indicator can be used to look at indications of production overshoot (or undershoot) during the simulation.

- **Chain speed efficiency.** Measures the percentage capacity utilization of the packing facility. The goal of the packer is to maximize the number of hogs going through the kill and cut floors. This ratio depends on the interaction between disassembly and economic capacity within the value chain. A chain speed efficiency greater (less) than one reflects economic expansion (contraction) relative to the initial level. The ratio is calculated by dividing the packing throughput by the packing capacity.

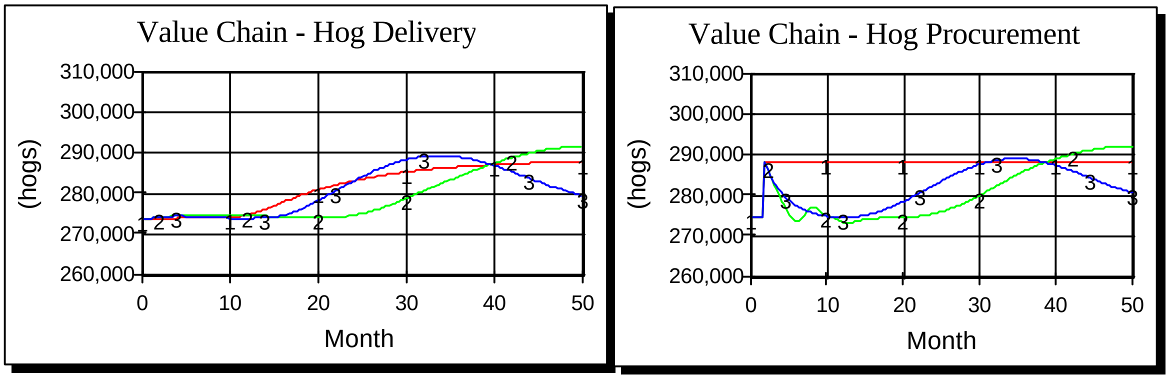

Figure 5. Simulation Results. Permanent demand change: Hog delivery and procurement

Under the assumption of no market feedback (curves labeled 1), the hog delivery graph in Figure 5 shows an exponential increase starting in month 12 that rises asymptotically to the procurement capacity level. This is the production response to desired hog procurement that begins with a step increase in month two. The time delay to increase production output to the capacity expansion is quite long, yet in the absence of economic feedback from the market all profit indicators are stable (see profit curves labeled 1 in Figure 6). Because there is no economic feedback involved (as would be the case in a partial budgeting approach) the influence of the business environment is ignored. The production expansion is quite smooth and the chain speed efficiency ratio shows that procurement goals are meet without overshoot.

As can be seen on Figure 5, under the price coordination mechanism (results with curves labeled number 2), the value chain production tends to overreact to the change in demand. This causes hog delivery to overshoot at month 38 relative to the five percent increase in demand. This can also be seen in Figure 6 in the production expansion ratio. Also, because the market is expanding production, margins are strongly sustained until the model returns to stability, ending at a lower level than initially. On the packing side the situation is different. The step increase in demand initially leads to a fulfillment of the chain speed capacity (1.05 in month two) from imports outside the value chain and at a higher price. The initial relative scarcity of hogs explains growing margins in production and declining margins at the packing level. However, consumer reaction eases the pressure on the live hog price, hence explaining declining margins at the production and increasing margins at the packing level (at around month 12), although the delivery of hogs do not begin until month 22. A higher live hog price impacts packing margins on the cost side, while enhancing production margins on the revenue side. As hogs begin to enter the market by month 22 their relative scarcity falls and is reflected by accelerated declining production and increasing packing margins. Negative packing margins breakeven at month 26 after more than 18 months in the red[2]. As packing margins recover the chain speed efficiency gains towards its full capacity of 1.05, with some overshoot (Figure 6). Margin patterns are consistent with economic theory as they tend to be higher for packing and lower for production when the supply of hogs are abundant and vice versa when the supply of hogs are low.

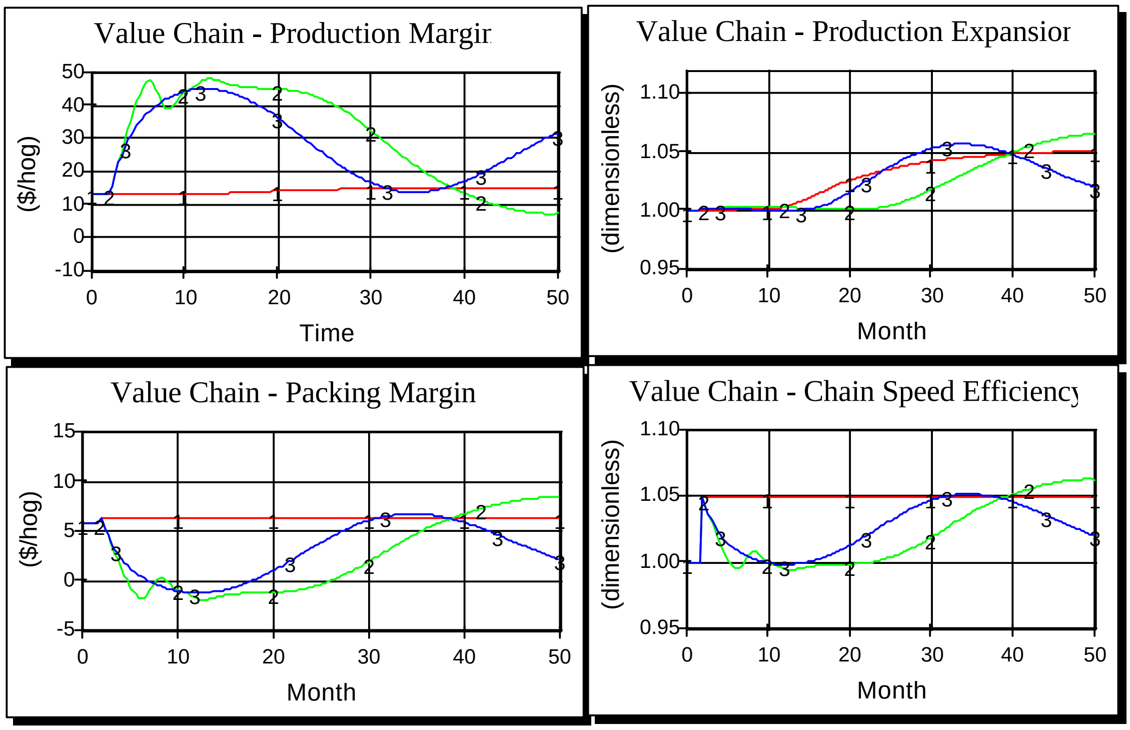

Figure 6. Simulation Results. Permanent demand change: Margins, production expansion and chain speed efficiency

Simulation results depicted by the curves labeled 3 in Figures 5 and 6 show the value chain behavior under the information feedback coordination mechanism. As seen in Figure 5, hog delivery and procurement reach their targeted levels by month 34 (month 34 corresponds to the period at which the business environment sector reaches stability). This result is reflected in the chain speed and production expansion ratios in Figure 6. In month 34 production margins meet the level that was obtained by the simulation of the value chain that had no market feedback without overshoot. Although slightly lower compared to the price coordination mechanism,

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2 Packers can experience long periods of negative margins (SARC, 1995; and discussions with consultants to agricultural industries have confirmed that pork packing margins were negative for the entire year 1996 and through the most part of 1997, as well, during a period of excess slaughtering capacity relative to hog supplies. This is similar to the situation depicted here.)

production margins are higher at month 34, the time by which the business environment becomes stable. Packing margins, on the other hand, do not remain negative to the same extend that they did under the price coordination mechanism. Clearly, the information feedback coordination mechanism provides a quicker response and a pattern of margins and output adjustment more consistent with the behavior of the business environment.

6. CONCLUSION

This paper has presented a summary account of a broader research effort to examine the role and timeliness of information transmission across a value chain in improving conformance. The value chain is modeled as part of a broader business environment that creates pressures on the coordination of dependencies across activities in a value chain. The results provide three key implications for strategy implementation. The first simulation showed what would be a path of adjustment to growth in the absence of economic feedback. The results were quite smooth but in a changing world that would lead the decisionmaker to a strategy implementation that may lack the robustness to address the temporal management of contraction and expansion phases. This reflects the limiting aspects of partial budgeting approaches to strategic planning (Lyneis, 1980). Second, the simulation assumed longer price information time delays within the chain to reflect an exclusive reliance on the live hog market price for decisionmaking. Longer time delays in responding to changing conditions within the business environment led to an overshoot of the target output – in addition, not shown here, excessive overshoot may lead to a decline in conformance quality and in lower margins (Cloutier *et al*., 1997b). Third, quicker information transmission through the chain led to a faster response on the part of producers and no overshoot was recorded in production. Short-run disequilibrium persists because of the ubiquity of long biological delays in production agriculture associated with upstream production, but its oscillatory amplitude is dampened by information feedback and the timeliness of information transmission at the hog delivery and procurement interface. Models like these can be used with industry participants as a learning tool to better understand how they can improve the coordination of inherent dependencies in the management of business activities. The underlying structure of this value chain model can be generalized to support the development of “shared vision” of other value chains that may involve the coordination of activities among many participants in food and agribusiness management and other areas as well.

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