Title: A synthesis of Austrian Economics and Complexity theory to Agricultural Structural change: An Application of an Agent-Based Modeling Approach

Assist. Prof. Desmond Ng, University of Alberta[1], Dept. of Rural Economy, 515 General Services Building, Edmonton, Alberta, Canada.

Associate Prof. Randall Westgren, University of Illinois at Urbana-Champaign, Dept of Agricultural and Consumer Economics, 302c Mumford hall, mc 710 1301 W Gregory Dr., Urbana, Il 61801, USA

Prof. Steven Sonka, University of Illinois, Urbana-Champaign, 170 National Soybean Research Center, 1101 W. Peabody Drive, Urbana, IL 61801, USA.

Abstract:

U.S. agricultural markets have undergone a tendency of structural change from open/spot market exchanges to an increasing prevalence of vertically coordinated market structures (Boehlje, 1995, 1999; Martinez, 1999; Barkema and Cook, 1993; Hurt, 1994; Drabenstott, 1994). The magnitude of this change has prompted inquiries to the development of new theoretical and analytical methods to the study of structural change processes in agri-food systems (Boehlje,1999). This is the subject of this research paper.

This paper presents a simulation using agent-based modeling of behavior of producers, processors, and life science firms. The behavior of agents (firms) draws upon the tenets of complexity science (Prigonine and Stengers, 1984) and Austrian economic notions of entrepreneurship and market processes (Kirzner, 1979, 1997; Hayek, 1967). The model is used to examine general tendencies towards market inertia and stability in Monte Carlo-style runs and the unexpected outcomes from entrepreneurial behavior that often lead to large-scale structural change – what complexity theorist call bifurcation of a normally stable system.

There are two principal findings of this agent-based simulation model. Due to the complex interactions in a supply chain market structure and the unpredictable behavior of alert entrepreneurs, structural change processes are sensitive dependent to the initial conditions of the market and the idiosyncratic choices of entrepreneurs. In addition, increasing contract premiums in vertically coordinated market arrangements do not appear to significantly generate changes in markets to exploit these incentives.

These findings fundamentally question social science's pre-occupation with models premised on an equilibrium orientation. Equilibrium behavior is only one possible expression of overall system behaviors. A spectrum of other behaviors exists to which new analytical methods and conceptual models are required to further understand and explain complex social systems. Agent-based modeling is argued as one such approach.

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1.0 Introduction

U.S. agricultural markets have undergone a tendency of structural change from open/spot market exchanges to an increasing prevalence of vertically coordinated market structures (Boehlje, 1995, 1999; Martinez, 1999; Barkema and Cook, 1993; Hurt, 1994; Drabenstott, 1994). Such changes involve fundamental changes in the pattern of production, marketing and organizational structure of the agri-food system. As understanding the nature of the changing face of agriculture becomes increasingly important, new theoretical and methodological approaches are sought (Boehlje, 1999). In particular, the transition to the greater coordination of markets renders a greater interdependence of activities among the life science, farmer production and processing sectors. This interdependence has yielded an increasingly complex market system as production decisions among farmer are no longer made in an atomistic setting but rather are increasingly influenced by the genomic advances in the life science sectors and the fragmented consumer demands confronted by the processor sectors. Consequently, theoretical and methodological approaches that capture the complexity of such a market system are increasingly warranted to understanding this changing face of agriculture.

The emerging science of Complexity is, thus, proposed to understanding agricultural structural change. Complexity science has been used to understand punctuated equilibria events (Kauffman, 1993, 1995; Gersick, 1991; White et al, 1997) to which radical changes arising from a complex system is argued to be reflective of the structural change in agricultural markets (Ng, 2001). Even though complexity science is based in the natural and physical sciences (Kauffman, 1993, 1995; Prigonine and Stengers, 1984), social science researchers are increasingly recognizing the merits of complexity perspectives to social science investigations (Anderson et al, 1988; Arthur et al, 1997; McKelvey, 1998a,b; Mathews et al, 1999; Stacey, 1992, 1995;

Wheatley, 1992 Waldrop, 1992). However, the application of complexity perspectives to the study of market structural change has been relatively limited. Hence, the objective of this paper is to bring forth the central properties of complex "social systems" by introducing a novel methodological approach to the study of the nature of structural change in agricultural markets. Agent-based modeling is used to express the ordering, "bifurcation" or structural changes, chaos, and emergent behaviors of complex system (Arthur et al, 1997; Axelrod, 1997; Epstein and Axtell, 1996; Kochugovindan and Vriend, 1998; Lane, 1993; Gaylord and D'Andria, 1998; Phelan, 1997;Vriend, 1999). Agent based modeling is, therefore, particularly suited towards understanding of the complex behavior involved in the changing face of agriculture.

Therefore, the objective of this paper is to present a simulation using agent-based methods to model the behavior of producers, processors, and life science firms. The behavior of agents (firms) draws upon the tenets of complexity science (Prigonine and Stengers, 1984; Jantsch, 1980; Mathews *et al*, 1999; Kauffman, 1993,1995; McKelvey, 1998a,b; Stacey, 1992,1994,1995; Wheatley, 1992) and Austrian Economics (Kirzner, 1979, 1997; Hayek, 1967). In the context of a supply chain system, this model is used to examine the transformation of commodity markets to vertically coordinated markets arrangements. Such a research investigation not only offers a unique methodological tool to the study of the complex behavior of "social systems" and thus forward the complexity paradigm with in social science research, but it also serves to address Boehlje's (1999) call for the development of alternative conceptual and analytical methods to the study of structural change in agricultural systems

1.1 Research Outline

This paper is organized into four sections. In drawing on Austrian economics, the behavior of agents is examined from the perspective of the subjective and alert entrepreneur

(Kirzner, 1979, 1997). This serves as the "behavioral basis" in constructing an agent-based simulation. The subsequent methodological section operationalizes this entrepreneurial behavior into an agent-based framework. Simulation results and conclusions on the nature of structural change in agricultural markets are discussed.

2.0 Conceptual Framework

2.1 Complexity theory and Agent Based Modeling

As a dominant method of complexity science, agent-based modeling[2] is concerned with the macro dynamical processes that emerge from the local interactions of adaptive or rule based agents (Arthur *et al*, 1997; Epstein and Axtell, 1996; Lane, 1993 Axelrod, 1997; Schelling, 1978; Kauffman, 1993,1995; Vriend, 1999; Kochugovindan and Vriend, 1998; Ferber, 1999; Weiss, 1999; Prietula *et al*, 1998; Phelan, 1997; Macy, 1997 a,b; Aversi *et al*, 1997; Dosi *et al*, 1998; Gaylord and D'Andria,1998; Goldspink, 2000). Based on a complex adaptive systems paradigm (Arthur et al, 1997; Anderson et al, 1988; Lane, 1993), an agent-based modeling approach relies upon the construction of computer simulations (Axelrod, 1997; Epstein and Axtell, 1996; Ferber, 1999; Gaylord and D'Andria, 1998; Lane, 1993; Weiss, 1999). These simulations are comprised of interacting heterogeneous and rule based agents that operate within artificial worlds (Lane, 1993). It is through this simulation approach that one can study the emergent properties expressed by the complex adaptive systems paradigm (Lane, 1993). In its application to economics, an agent-based approach is characterized as:

> "Agent-based computational economics (ACE) is roughly characterized as the computational study of economies modeled as evolving decentralized systems of autonomous interacting agents. A central concern of ACE researchers is to understand the apparently spontaneous formation of global regularities in

[2]It is also termed as simulating artificial life (Macy, 1997b).

economic processes, such as the unplanned coordination of trade in decentralize market economies that economists associated with Adam Smith's invisible hand. The challenge is to explain how these global regularities arise from the bottom up, through the repeated local interactions of autonomous agents channeled through socio-economic institutions, rather than from fictitious top-down coordination mechanisms such as imposed market clearing constraints or an assumption of a single representative agents. ACE is thus a specialization to economies of the basic complex adaptive systems (CAS) paradigm."(Tesfatsion, 1998, ACE Web site)

Hence, an important research goal of an agent-based approach is the study of the "bottoms-up" or decentralized interactions of agents that yield the emergence of higher level macro structures and behaviors (Lane, 1993). Such behaviors involve the expression self-organized behaviors to which order arises from chaos. While conversely, the interactions among agents that yield such self-organizing behavior can also give rise to the expression of chaos from order. The interplay of non-linear and endogenous interactions consisting of positive (i.e. disequilibrating) and negative (equilibrating) feedback influences yields chaotic and ordering behavior (Jantsch, 1980; Prigonine and Stengers, 1984; Ng, 2001; Marion, 1999; Stacey, 1992).

2.2 Bifurcation Event and Structural Change

The alternation between chaos and order is marked by a "bifurcation event". A "bifurcation event" refers to fundamental decomposition in the system's structure arising from non-linear positive feedback influences (Gemmill and Smith, 1985; Gersick, 1991; Jantsch, 1980; Kauffman, 1993,1995; Leifer, 1989; Prigonine and Stengers, 1984; Marion, 1999; Stacey, 1992, 1995). At this point of a bifurcation, a "symmetry breaking process" occurs (Smith and Gemmill, 1991) where an abrupt or rapid alteration in the system's structure arises (Prigonine and Stengers, 1984; Jantsch, 1980; Kauffman, 1993; McKelvey, 1998b; Leifer; 1989; Smith and Gemmill, 1991; Gemmill and Smith, 1985; Dopfer, 1991; Macintosh and Maclean, 1999).

To elaborate, when a complex system becomes sufficient perturbed by the positive feedback interactions of a complex system, it enters a “far from equilibrium” state (i.e. disequilibrium) (Prigonine and Stengers, 1984; Jantsch, 1980; Stacey, 1992, 1995). In this disequilibrium state, the complex system is confronted by a "bifurcation" event where new opportunities for the reconfiguration of the internal arrangement of a complex system arise (Prigonine and Stengers, 1984; Jantsch, 1980; Kauffman, 1993,1995; Leifer; 1989; Smith and Gemmill, 1991; Gemmill and Smith, 1985; Dopfer, 1991). That is, with out external intervention, a process of “self-organization” occurs where the exploration of new internal configurations by the components of a complex system (i.e. agents such as people) leads to the spontaneous emergence of a new complex order (Jantsch, 1980; Prigonine and Stengers, 1984; Mathews et al, 1999; White et al, 1997; Kauffman, 1993, 1995; Hayek, 1967; Leifer, 1989; Stacey, 1992, 1995).

Although this bifurcation event generates new complex arrangements, this arrangement cannot be predicted (Kauffman, 1993; Jantsch, 1980; Prigonine and Stengers, 1984, Mathews *et al*, 1999; Stacey, 1995; Marion, 1999; Laszlo, 1987). As a complex system undertakes a process of “self-organization”, the trajectory to which a new order emerges is “sensitive dependent” to the initial conditions occurring in the bifurcation event (Jantsch, 1980; Prigonine and Stengers, 1984). In particular, these initial conditions stem from the stochastic behavior of agents where their behavior is self-amplified through positive feedback to influence the trajectory at which new complex systems are formed. Since these initial conditions cannot be known and that positive feedback influences render prediction an impossible event (Thiertart and Forgues, 1995), the formation of this new complex order is unpredictable (Jantsch, 1980; Prigonine and Stengers, 1984; Stacey, 1995; Marion, 1999; Laszlo, 1987; Anderson, 1999). As Laszlo notes,

> "when dynamic systems are destabilized and pass through a chaotic phase on the way toward essentially new -and in practice unpredictable- steady states...During this phase, the bifurcating systems are sensitive to minute change: the smallest variation in an initial condition can give rise to widely different outcomes."
> (Laszlo, 43,1987)

The implication of the complexity notion of "bifurcation" is that structural change in agriculture is unique to the particular historical idiosyncrasies of the industry in question. Due to the sensitive dependent property of complex systems, the individual behavior of agents such as a life science firm, farmer/producer, or a single processor can have dramatic influences that alter the entire industry's evolutionary trajectory. Thus, structural change processes in each agricultural market is unique to the initial and subsequent sequence of behavioral choices of its participants and, therefore, the structural change processes of any given agricultural market are non-repeatable. This dictates that the evolution of agricultural markets such as in hogs and soybeans can never re-enact the dramatic changes observed in the broiler industry. As a result, this has significant implications to social policy where actions employed in one market cannot be redeployed in another market to "recreate" past historical events.

2.3 Merits of Agent-based Modeling

In light of the bifurcated behaviors of complex systems, an important feature of the agent-based approach is it's emphasis on the stochastic behavior of rule based agents and its attention to their non-linear interactions enables the expression of this complex behavior. Such behavior is not expressible by other methodological approaches that rely on analytical mathematical methods (Axtell, 2000). This is because the non-linear behaviors of complex systems render the solutions to analytical mathematical models (i.e. solving a system of equations) intractable and therefore such models cannot express the spectrum of complex behaviors afforded from agent-based methods.

Another merit of agent-based models is it operationalizes the Austrian view of market processes. One of the contributions of the Austrian economic school was its challenge to the equilibrium conception of neoclassical economics (Hayek, 1945; Kirzner, 1997). Unlike the equilibrium state espoused by perfect competitive markets, Austrians contend that markets are fundamentally a non-equilibrium process driven by the subjective behavior of entrepreneurs (Kirzner, 1997). According to Hayek (1948, 1967, 1978), the expression of "social order" arises from the process of interactions among heterogeneous knowledge entrepreneurs. In addition, just as a social order can spontaneous emerge from the collective interactions of entrepreneurial (Hayek, 1967, 1978), this order can be de-constructed through Schumpeter's "creative destructive" force.

However, in so far as Austrian were active in proponents to this decentralized characterization of market processes, one of the important criticism of the Austrian economic school is the lack of a methodological approach in operationalizing this non-equilibrium and decentralized view of market process. Given that both Austrian economics and agent based models are concerned with the decentralized or "bottoms-up" (Lane, 1993) processes, the conceptual foundations of the Austrian school is consistent with the complex properties of agent-based models. As a result, agent based modeling is particularly suited to operationalizing this Austrian conception and thus provides a unique methodology for the Austrian school.

2.4 Agent-Based Modeling and Austrian Economics

In operationalizing the decentralized and non-equilibrium view of the Austrian economic school, the subjective and alert entrepreneur is used to characterize the heterogeneous and adaptive behavior of agents. In addition, social network theory is employed to inform the nature of their social interactions. These social interactions will serve to depict the non-linear interactions found in agent-based models.

2.4.1 Heterogeneous Knowledge: Subjectivism

According to the Austrian economic tradition, entrepreneurial behavior is subjective. Subjectivism is not only the foundation but also the unifying theme of the Austrian economic school (Ebeling, 1990).

> "the subjective approach to economic phenomena builds economic analysis upon the insight that every individual chooses and acts purposefully (i.e. in pursuit of his purpose and according with his perceptions of his options for achieving them" (White, 371, 1990).

As a result, an individual's knowledge and perception of the world is fragmented and differs among individuals (Hayek, 1945, 1967; Fleetwood, 1995). Thus, the heterogeneity of agent behavior is with respect to the diversity or fragmented knowledge experiences of entrepreneurs. This fragmented knowledge is defined with respect to an entrepreneur’s past capital plan choices. A capital plan is defined as a course of action that employs the use of an agent's subjective knowledge in the choice of combinations of capital inputs (physical and human capital) for the production of output. Since the subjective imaginations of an entrepreneur are employed in the creation of capital plans, these plans –especially innovative plans- are largely unpredictable. This accords with the "stochastic idiosyncratic" property of agent behavior (McKelvey, 7, 1998b). In addition, as an entrepreneur's interpretation of information and its “alertness” (Kirzner, 1979, 1997) to risk is idiosyncratic to one's subjective experiences, the accumulation of knowledge experiences over time is also idiosyncratic. Therefore due to the subjective premise of the Austrian school, this path dependent behavior yields the development of heterogeneous knowledge among entrepreneurs.

2.4.2 Adaptive Behavior:

Another aspect of agent behavior is their ability to adapt through the use of behavioral rules or decision heuristics (Epstein and Axtell, 1993; Gaylord and D'Andria, 1998; Vriend, 1999; Lane, 1993). These rules depict the "bounded rationality" (Simon, 1976) of agent choices (Axtell, 2000). Arising from the imperfect and subjective knowledge of entrepreneurs, entrepreneurs are governed by two types of behavioral rules. Rule following behavior reflects a passive or non-purposive aspect of entrepreneurship. It captures an entrepreneur's aversion to market uncertainty by adopting established plans in the market. This adoption of established plans has often been described as "bandwagon effects" or conformance pressures for social legitimacy (DiMaggio and Powell, 1983). Such aversion to uncertainty leads to the formation of stable and resilient social institutions (DiMaggio and Power, 1983).

However, since entrepreneurship involves more than reactive responses, the entrepreneur is also "alert" to grasping for unnoticed market opportunities availed in uncertain markets (Kirzner, 1979; 1997). The alert aspect of entrepreneurship involves an uncertainty taking function (Kirzner, 1997). Entrepreneurial alertness,

> "refers to an attitude of receptiveness to available (but hitherto overlooked) opportunities. The entrepreneurial character of human action refers not simply to the circumstance that action is taken in an open-ended, uncertain world, but also to the circumstance that human action is at all time spontaneously on the lookout for hitherto unnoticed features of the environment (present or future)" (Kirzner, 72,1997).

Through entrepreneurial alertness, the uncertainty taking efforts of the alert entrepreneur employs his private knowledge to formulate a plan in "grasping" (Kirzner, 1997) for unnoticed market opportunities to which through experimentation expands the space of opportunities in a market.

As a consequence of alertness, entrepreneurs exhibit rule generating behaviors. Rule generating behavior is founded on the alert efforts of entrepreneurs to experiment and, therefore, innovate novel plans. One example of rule generation is Schumpeterian innovation (Schumpeter, 1951) where novel combinations of capital inputs are rearranged to produce innovative products/processes (Brouwer, 1996; Ng, 2001). Hence, unlike rule following behavior, alertness leads to the creation of new plans in a market and is a primal source to disrupting the stability of markets. In that, by creating innovative plans, the entrepreneur plays an active role to the "creative destruction" of markets (Schumpeter, 1951).

2.4.3 Non-linear Behaviors: Social Networks and Social Interactions

Closely tied to behavioral rules are interaction rules. As interactions are important to the expression of emergent behavior (Lane, 1993), agents have interaction rules that prescribe the manner at which they interact with other agents (Epstein and Axtell, 1996; Lane, 1993; Gaylord and D'Andria, 1998). These interactions are local in nature and thus contribute to the boundedly rational behavior of agents (Axtell, 2000). With in "social networks", non-linear interactions arise from the transmission of the subjective knowledge of entrepreneurs with in such a network (Ng, 2001). In defining a social network, it consists of strong and weak information ties (McPherson et al, 1992; Granovetter, 1973). Strong ties are information ties to agents with similar knowledge, while weak information ties are ties to agents with different knowledge (Granovetter, 1973; McPherson et al, 1992, Ng, 2001; Stacey, 1992). An entrepreneur's interaction rule involves the formation of strong and/or weak information ties.

As defined by an entrepreneur's interaction rule, the non-linear behavior of a social system arises from the social interactions of rule following and rule generating entrepreneurs. Social interactions involve the transmission of the knowledge of plan choices where plan choices arise from the rule following and rule generating behavior of entrepreneurs. Rule following behavior is conducive to the formation of social networks that contain strong information ties (Ng, 2001). Due to the uncertainty of complex market systems, an entrepreneur's decision to conform or adopt the plans of other similar entrepreneurs (i.e. rule following) serves to reduce the uncertainty of trying new ventures (Scott, 1995). As a result, rule following behavior is strongly associated with the formation of strong information ties. Since strong information ties are conducive to converging or equilibrating tendencies (McPherson et al, 1992; Ng, 2001; Stacy, 1992), the non-linear interactions involving the transmission of the knowledge of these established plans lead to negative feedback (Ng, 2001).

Conversely, rule generating behavior involves the creation of social networks that contain weak information ties and leads to divergent or positive feedback tendencies (Ng, 2001). The creation of innovative plans from rule generating behaviors is positively influenced by the diversity of agent interactions because Schumpeterian innovations are based upon the recombination of plans choices among diverse entrepreneurs (Loasby, 1999; Ng, 2001). As a result, rule generating behaviors is strongly associated with the construction of weak information ties. This yields the onset of positive feedback influences. That is, since weak information ties expose an entrepreneur to a diversity of plan choices (i.e. diversity of knowledge choices), the creation of innovative plans reinforces the further generation of increasingly diverse capital plans. This is because the recombination of the diversity of knowledge experiences generates Schumpeterian innovations and in turn the recombination of these innovations through weak information with other innovative plans leads to its further generation. (Ng, 2001). Hence, as innovative plans are created through rule generating behaviors, the diffusion of these plans among other rule-generating entrepreneur leads to the further generation of innovative plans.

3.0 Methodology

3.1 Agent's Decision Variables

The behavior of the alert and subjective entrepreneur is used to operationalize the behavior of the artificial agents with in an agent-based simulation framework. In describing the agent/entrepreneur's[3] behavior, the entrepreneur is confronted with three decision choices. An agent chooses capital combinations, X, where X is a vector of 8 capital choices, x. These input choices constitute an entrepreneur's capital plan, cp, that is used produce an output product indexed by i[4]. In deriving an entrepreneur's plan, it is determined by its choice of behavioral and interaction rules (BRIR). Specifically, an entrepreneur's choice of interaction rule determines its social network. Based on this social network, the entrepreneur's choice of behavioral rule is then used to devise different combinations of input use in generating different plans. With an entrepreneur's choice of plan, the agent is then confronted with a product-market choice. This involves the choice of three product-markets (commodity, VC1 and VC2) involving different market arrangements.

The entrepreneur's three decision choices are interdependent events and are captured in an agent's tradeoff function. This function is used to evaluate an agent's perceived profit and is a critical component to expressing the alert and subjective behaviors of the Austrian entrepreneur.

3.2 Entrepreneur's Heterogeneous Knowledge

Before examining an entrepreneur's trade-off function, the heterogeneous knowledge of entrepreneurs is operationalized by three agent attributes. Table 1 provides a description of these attributes.

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3 The term agent and entrepreneur will be used interchangeably.
4 i=1 (Commodity), 2 (VC1), 3 (VC2)

Table 1: Entrepreneur's Knowledge Attributes

Attribute Name	**Attribute Description**
1) Market Change Probability: $MCP_{s,k,}(i_t)$	The probability of an entrepreneur changing to a different product-market arrangement.
2) Aspiration Level: $Asp_{s,k}\,(i_t)$	An entrepreneur's aspiration level measures the willingness for an entrepreneur to change his existing capital plans and product market arrangement. It is defined as the average profitability of plans in a given product-market.
3) Entrepreneurial Memory	Memory of the profitability of past plans for each product-market an entrepreneur has participated in.

The heterogeneous knowledge of entrepreneurs is defined with respect to the experience of past plan and product-market choices. This experience is measured in terms of the past profits earned by the entrepreneur's product-market and capital plan choices. This experience is unique as subjectivism yields path dependent behavior. As latter discussed in the tradeoff function, an entrepreneur’s subjectivity is incorporated into each of these choices and the outcome of these subjective choices is reflected by profits earned. The earned profits contribute to the heterogeneity of entrepreneurial knowledge in the market place. In that, this heterogeneity is captured by the entrepreneur's memory as the profitability of past plan and product-market choices.

Calculated from an entrepreneur's memory of profitable and not so profitable plans, another dimension highlighting the heterogeneity of an entrepreneur's knowledge is its market change probability, $MCP_{s,k,}(i_t)$ (attribute 1). Based on an entrepreneur's T time periods of experience, the market change probability measures an entrepreneur's propensity to change to product-market type i. Equation 1 defines an entrepreneur k's market change probability for product-market i, $MCP_{s,k}\,(i_t)$, at supply stage s and at simulation time period, t.

Equation 1

$$MCP_{s,k}(i_t) = \frac{\sum_{t=1}^{T}\sum_{cp}\Pi(CP_{s,t,k} \mid i_t)}{\sum_{i}\sum_{t=1}^{T}\sum_{cp}\Pi(CP_{s,t,k} \mid i_t)} \qquad \forall\ s = stage,\ i = product\ market, k = agent\ ,\ t = time$$

For a supply stage s and simulation time period t with a given product-market choice i_t, equation 1 is derived as the sum of entrepreneurial profits, ? ($CP_{s,t,k}$ |i_t), for T periods of agent experience over all plans choices, $cp_{s,t,k}$, in product-market i_t at supply stage s. This is divided by the cumulative entrepreneurial profits for all product-markets an entrepreneur has participated in. This is shown by the denominator of equation 1. With equation 1, an entrepreneur k earning high entrepreneurial profits in any given product-market, i_t, will have a greater propensity to choose to enter that product-market. This also creates a path dependent process in an entrepreneur's choice of product markets.

Another heterogeneous attribute is an entrepreneur's aspiration level, $Asp_{s,k}$ (i_t). An entrepreneur's aspiration is the profit expectation placed on product-market, i_t , at time t. Aspirations are a measure of an entrepreneur's alertness to profit opportunities in the market environment[5]. Specifically, an entrepreneur's aspiration or alertness is used to determine an agent's propensity to undergo changes in plans, behavioral and interaction rules (BRIR), and product-market choices. An agent with high aspiration levels has a greater tendency to undergo such decision choices in the expectation that these choices generate greater entrepreneurial profit. This serves to reflect the alert behavior of the Austrian entrepreneur. That is, the propensity to undertake these decision choices is positively influence by an entrepreneur's subjective assessment of market opportunities. Therefore, for a given supply stage s and time period t, an entrepreneur k's aspiration for product-market i_t, $Asp_{s,k}$ (i_t), is shown in equation 2

Equation 2

$$Asp_{s,k}(i_t) = \frac{\sum_{t=1}^{T}\sum_{cp}\Pi(cp_{s,k,t} \mid i_t)}{\sum_{t=1}^{T} No.cp_{s,k}(i_t)} \qquad \forall\, s,k,t$$

An entrepreneur's aspiration is calculated as the average entrepreneurial profits earned for a given product-market choice, i_t. It is the sum of the agents entrepreneurial profits for all plans, cp, chosen with in a given product-market choice i_t for the T periods at which an agent has participated in product-market, i_t. This numerator is divided by the frequency or total number of plans, No. $cp_{s,k,}(i_t)$, for T periods of entrepreneurial experience in product-market, i_t , at simulation time period t. The entrepreneur’s aspiration, thereby, yields its expected or average entrepreneurial profits for a product-market, i_t.

The heterogeneous knowledge of agents is, thereby, modeled through an agent's attributes of memory, market change probability and aspiration level. This heterogeneity of knowledge accords with the "fragmented" knowledge in society described by Hayek (1945). It is based on the diversity of entrepreneurial knowledge that enables the market discovery process to reveal plans that are profitable (Hayek, 1978a). In such a process, each entrepreneur is incented to utilize their idiosyncratic knowledge to reveal successful plans in the market (Hayek, 1978; Fleetwood, 1995). It is through a trial and error experimentation process that markets are characterized as a competitive discovery process (Hayek, 1978)

3.3 Entrepreneur's Trade-off Function: Decision Choices

Guided by the heterogeneous knowledge of the entrepreneur, the adaptive behavior of the alert and subjective entrepreneur is operationalized through a trade-off function. An entrepreneur's trade-off function captures the cumulative knowledge experiences and subjective

5 The market environment consists of the commodity, VC1 and VC2 product markets and capital plans.

perceptions used in evaluating profit opportunities in the market. This trade-off function yields the expression of an agent's choice of capital plan, BRIR (i.e. rule-following and rule-generating behaviors and social interaction rules) and product-market choices.

A tradeoff function is defined for each entrepreneur k at each supply stage s and evaluated for each time period, t. For a given choice of product-market, i_t, and behavioral and interaction rule ($BRIR_t$) choice, the tradeoff function assigns a value to the entrepreneur's choice of combination of inputs uses in its capital plan. These input choices are influenced by both the entrepreneur's subjective perceptions and its past experiences. Equation 3 defines an agent's trade-off function[6].

Equation 3

$$Tradeoff_{s,k,t}(X_t^* \mid i_t, cp_t^*, BRIR_t^*) =$$

$$\left[P_{s,t}(h_{s,t} \mid i_t)\, F_{s,k,t}^{Perceived}(X_t^* \mid i_t, cp_t^*, BRIR_t^*)\right] - \sum_x R_{s,x,t}(i_t)\begin{bmatrix}(X_{t-1} \mid i_{t-1}, cp_{t-1}, BRIR_{t-1}) \\ -(X_t^* \mid i_t, cp_t^*, BRIR_t^*)\end{bmatrix}$$

$$- Asp_{s,k,t}(i_t) + \left[Wgt_{s,k,t}(cp_t^* \mid i_t)\, Wgt\Pr ob_{s,k,t}(cp_t^* \mid i_t)\right] \quad \forall s,k,t$$

<u>3.3.1 Trade-off Function: Output and Input Prices</u>

In describing the price variables of the trade-off function, $P_{s,t}$ ($\eta_{s,t} \mid i_t$) and $R_{s,x,t}$ (i_t) denote the output and input prices respectively. $P_{s,t}$ ($\eta_{s,t} \mid i_t$) is the output price for a given product-market choice, i_t, at supply stage s at time t. This output price is a function of an excess demand/excess supply, $\eta_{s,t}$, at supply stage s at time t. This excess demand/supply function, $\eta_{s,t}$, is derived as the difference between the adjacent downstream demand and the output supply to this adjacent downstream stage. While, $R_{s,x,t}$ (i_t), denotes the input prices associated with input x

6 * denotes the current choice made by the entrepreneur. The absence of * denotes either a non-choice variable or a choice variable to made in a latter sequence of series of decisions (i.e. i_t).

at supply stage s at time t. Since the input prices of an adjacent downstream stage must equal the output prices facing the adjacent upstream supply stage, the following equality condition is set.

Equality 1

$$R_{s,x,t}(i_t) = P_{s^{upstream},t}(\eta_{s^{upsream},t} \mid i_t) \qquad \forall x, s, s^{upstream}, t$$

3.3.2 Trade-off Function: Perceived Production Function

Although these output/input prices incent alert behavior, there are additional factors that influence an entrepreneur's alertness to opportunities in the market. One of these factors is an entrepreneur's subjectivity. This subjectivity is reflected in the trade-off function through a perceived production function, $F_{s,k,t}^{Perceieved}$. This perceived production function is a Cobb-Douglas production function separable in eight input uses. This is shown in equation 4.

Equation 4

$$F_{s,k,t}^{Perceived}(X_t^* \mid i_t, cp_t^*) = \left[\sum_{x=1}^{8} A_{s,i,x,t}^{Percieved} \; X_{s,i,x}^{a_{s,i,x}} \right] \qquad \forall s,k,t$$

Given an agent's choice of product-market, i_t, and plan, cp_t^*, this perceived production function yields the amount of output produced from entrepreneur k's choice of inputs, X_t^*,[7] for a given supply stage s at time t. Specifically, an entrepreneur makes eight binary choices (1=to use input x^*, 0=not to use input x^*) that determine the combinations of inputs used in their capital plan. Entrepreneurs also choose the amounts of each input used and thus inputs take on a real value. This perceived production function also contains parameters $a_{s,i,x}$ and $A^{Perceived}_{s,i,x,t}$. $a_{s,i,x}$ is a parameter with a range of value $0< a_{s,i,x} <1$ whose sum is less than 1 such that the production function exhibits decreasing returns technology. While the variable $A^{Perceived}_{s,i,x,t}$ is the marginal

7 X^* is a vector containing 8 capital inputs, x^*, where * denotes the current choice of input use.

product coefficient of input x used in product-market i_t for stage s at time t[8]. An entrepreneur's subjective perception is captured by this variable. In that, an entrepreneur's subjectivity is introduced through its subjective perceptions on the marginal product contributions of input use. These subjective perceptions influence the amount of capital use as well as the combination of capital used. This in turn influences the entrepreneur's choice of capital plan, cp_t, and its subsequent profitability of this capital plan, cp_t, choice.

<u>3.3.3 Trade-off Function: Subjectivity on the Marginal Product of Input use</u>

To incorporate an entrepreneur's subjectivity into this perceived marginal product variable, $A^{Perceived}_{s,i,x,t}$, a random disturbance term[9] is used to adjust the "true" or objective value of the marginal product of input use, $A_{s,i,x,t}$. Hence, deviations between the perceived marginal product from the objective marginal product value defines the extent of entrepreneurial subjectivism or error. However, in order to operationalize an entrepreneur's subjectivity, the objective marginal product variable, $A_{s,i,x,t}$, is defined.

<u>3.3.3.1 Trade-off Function: Objective Marginal Product</u>

The objective marginal product, $A_{s,i,x,t}$, exhibits a dynamic property accounting for technological uncertainty and learning curve effects. This behavior is demonstrated by equation 5.

Equation 5

$$A_{s,i,x,t} = A_{s,i,x}Init + \left\{ \frac{pop_{s,i,x,t}}{\sum_{X} pop_{s,i,x,t}} \right\}^2 s_{s,i,x} A_{s,i,x}Init + \left\{ \frac{pop_{s,i,x,t}}{\sum_{X} pop_{s,i,x,t}} \right\}^2 A_{s,i,x}Init \qquad \forall s,i,x,t$$

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8 Although $A_{s,i,,x,,t}$ $\alpha_{s,i,x}$ is the marginal product for this Cobb-Douglas production function, for simplicity, we refer $A_{s,i,x,t}$ as the marginal product coefficient. This is because $\alpha_{s,i,x}$ is a parameter in the model.

9 This has a uniform distribution with a mean of 0 and a standard deviation of 1.

The objective marginal productivity, $A_{s,i,x,t}$ is adjusted by altering the initial marginal productivity parameter $A_{s,i,x}$ Init values by these two effects. This initial marginal product parameter, $A_{s,i,x}$ Init, is defined by a matrix of values that specifies the initial marginal products for each input, X, found in each product-market i_t at supply stage s. The second term of equation 5 captures the technological uncertainty associated with the adoption of input X_t^*. Inputs that have not been extensively used are subjected to greater degrees of uncertainty. The extent of this uncertainty is reflected by a disturbance term $\sigma_{s,i,x}$ with an equal probability of exhibiting positive and negative values[10]. As the proportion of entrepreneurs who employ input X_t^* increases (i.e. increases the ratio of the population variables, $pop_{s,i,x,t}$,[11] in the second term), the uncertainty associated with the use of this input X_t^* declines. This reduction in uncertainty reduces the disturbance on the initial marginal product parameter $A_{s,i,x}$ Init by a factor of $\sigma_{s,i,x}$. As the adoption of the input X_t^* continues, learning curve effects are captured in the third term. As the proportion of entrepreneur employing input X_t^* increases, it revises upward the initial marginal product coefficient, $A_{s,i,x}$ Init. That is, the increased use of a particular input provides for greater efficiency gains. Through both terms in equation 5, the technological uncertainty and learning curve effects associated with input X_t^* is modeled.

3.3.3.2 Trade-off Function: Subjective Marginal Product

Based on this "objective" marginal product function, $A_{s,i,x,t}$, (equation 5) an entrepreneur's subjectivity is introduced through equation 6. Equation 6 adjusts the "objective"[12] marginal

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10 As an example, with $\sigma_{s,i,x}$=2.5, it has a 50% probability of being -2.5 and a 50% probability of being +2.5.
11 $pop_{s,i,x,t}$ denotes the population of entrepreneurs who employ input X for a given product-market choice at stage s in time t where its sum denotes the total use of all inputs in that product-market.
12 These values are true in so far as they are used to calculate an agent's entrepreneurial rents. That is, these are the market system's valuation of the marginal product of capital use.

product values, $A_{s,i,x,t}$, by a random disturbance term that has a uniform distribution with a mean of 0 and a standard deviation of +1 and -1.

Equation 6

$$A^{Perceived}_{s,i,x,t} = \left[1 + Uniform(0,1) \right] A_{s,i,x,t} \qquad \forall\, s, i, k, t$$

By substituting the entrepreneur's subjective perceptions of marginal products, $A^{Perceived}_{s,i,x,t}$, into the entrepreneur's production function (equation 4), one yields the perceived production function, $F_{s,k,t}^{Percieved}$, shown in the trade-off function. Hence, by including these subjective perceptions, it influences the choice of input combinations used in an entrepreneur's plan. That is, an entrepreneur's subjective perceptions of the marginal product of input use leads to idiosyncratic plan choices and thus contributes to generating the heterogeneous knowledge in the market (Ng, 2001).

3.3.4 Trade-off Function: Application of a Classifier system to an Entrepreneur's Experience

Due to subjectivism, entrepreneurial behavior often involves much trial and error experimentation where experience of past success/failure is utilized to inform the choice of more successful plans (Hayek, 1978a; Kirzner, 1979, 1997). Hence, in order to model an entrepreneur's ability to draw on its past experience, John Holland's (1995) “classifier system” is applied within the context of the entrepreneur's trade-off function. A classifier system draws upon the entrepreneur's memory of the profits of past plan choices to which this experience influences the current and subsequent choice of plans. Specifically, with a classifier system, plans earning high profits have a greater tendency to be reinforced or used. While plans that have earned low entrepreneurial profits are avoided. As a result, through this classifier system, the guidance influence of an entrepreneur's past experience is employed. This is achieved through a weighting function in the tradeoff equation. This weighting function, $Wgt_{s,k,t}$ is defined by equation 7

Equation 7

$$Wgt_{s,k,t}(cp_t^* \mid i_t) = \frac{\sum_{t=1}^{T} \Pi_{s,k,t}(X_t^* \mid i_t, cp_t^*)}{No.CP_{s,k}^*(i_t)} \qquad \forall\ s,k,t$$

For a given product-market choice, i_t, and a capital plan choice, cp^*_t, containing capital inputs, X_t^*, at time t, the weighting function, $Wgt_{s,k,t}$ $(cp_t^*|i_t)$ yields the average entrepreneurial profits for the chosen plan, cp_t^*, for an entrepreneur k in supply stage s. It is calculated as the cumulative entrepreneurial profits over T periods of entrepreneurial experience for the chosen plan, cp_t^*[13] in product-market, i_t , at time t divided by the total number of times an entrepreneur has used that plan, No. $CP^*_{s,k}$. This weighting function yields an entrepreneur's perceived average profits for its choice of plan, cp_t^*. However, to develop an entrepreneur's expected value of this capital plan, the perceived profitability of this plan, $Wgt_{s,k,t}$ $(cp_t^*|i_t)$ is multiplied by the probability of this plan being used, $WgtProb_{s,k,t}$ $(cp_t^*|i_t)$. This was included as to favor those plans that have been used more often. Therefore, entrepreneurs may not choose capital plans, cp_t^*, purely on the basis of its profitability. Equation 8 is used to derive this "perceived" probability.

Equation 8

$$Wgt\,\mathrm{Pr}\,op_{s,k,t}(cp_t^* \mid i_t) = \frac{\sum_{t=1}^{T} No.CP_{s,k}^*(i_t)}{\sum_{t=1}^{T}\sum_{cp} No.CP_{s,k}(i_t)} \qquad \forall\ s,k,t$$

For given a choice of product-market, i_t, at time t, $WgtProb_{s,k,t}$ is the ratio of the frequency of the chosen plan, No. $CP^*_{s,k}$, over T periods of entrepreneurial experience divided

13 Where X_t^* denotes the combination of inputs used in this plan.

by the total number of plans employed over T periods of entrepreneurial experience used in product-market, i_t , at time t. This ratio yields the likelihood of choosing a given plan among all other plans used in a given product-market, i_t. By taking the product of $Wgt_{s,k,t}$ (equation 7) and $WgtProb_{s,k,t}$, (equation 8) an entrepreneur's expected profitability for its chosen plan, cp^*_t, is derived for each time period t. This expected value becomes an addition to the entrepreneur's tradeoff function.

By incorporating this classifier system within the tradeoff function, the chosen plans with a high expected value increases the value of the trade-off function such that this increases the propensity to use the chosen plan. Conversely, if a plan is unsuccessful, the lower expected value lowers this tradeoff value. Thus, an agent will have the tendency to avoid repeating the use of this chosen plan. This generates behavior among entrepreneur's to avoid repeating past errors such that this enables the entrepreneur to concentrate its search efforts to alternative plans offering higher profits. As a result, through the use of this classifier system, the guidance/constraining influence of an entrepreneur's past experience plays an important role to alert entrepreneurship.

3.3.5 Trade-off Function: Revenue and Cost components

The entrepreneur's trade-off function contains the entrepreneur's perceived revenue and cost of input use. For a current capital plan choice, the revenue consists of the product of output prices, $P_{s,t}$ ($\eta_{s,t}$ | i_t) and its perceived production function, $F_{s,k,t}^{\,Perceived}$, plus the expected profitability of a given plan that is defined by the classifier system. With respect to the cost of input use, for a given product-market choice, i_t, the input cost is calculated as the sum of the product of input prices, $R_{s,x,t}$ (i_t), and changes in input use from change in capital plan choices.

This input cost is based on a change in the usage of inputs because we assume entrepreneurs have an initial endowment of capital use. Hence, the cost of capital use is based on the changes in capital use occurring over the entrepreneur's experience. This is shown with equation 9.

Equation 9

$$CapitalCost_{s,k,t}(X_t^* \mid i_t, cp_{t-1}, cp_t^*) = \sum_x R_{s,x,t}(i_t)\left[(X_{t-1} \mid i_{t-1}, cp_{t-1}) - (X_t^* \mid i_t, cp_t^*)\right] \qquad \forall s,k,t$$

3.3.6 Trade-off Function: Entrepreneurial Aspirations

The last aspect of the entrepreneur's tradeoff function is the addition of an entrepreneur's aspiration level, $Asp_{s,k}(i_t)$. This addition captures an entrepreneur's alertness for those plans that earn above-normal entrepreneurial profits. With in the calculation of an entrepreneur's trade-off function, an entrepreneur's aspiration level is subtracted from the difference of the revenue and cost components of the entrepreneur's trade-off function. This difference reflects the extent to which the entrepreneur's subjective entrepreneurial profits associated with its choice of plan, cp^*_t, exceeds or falls below its aspiration level, $Asp_{s,k}(i_t)$. Since an entrepreneur's average entrepreneurial rents in a given product-market, i_t, is measured by its aspirations, the amount exceeding this value denotes the above-normal returns to alertness. Those plans that yield high "perceived" profitability (i.e. perceived profitability is the sum of the profit components and classifier system values of the tradeoff function) reflect plans that exceed the average entrepreneurial profits earned in that product-market. This leads to a greater propensity for agents to utilize its chosen plan, cp^*_t. On the other hand, if the profitability of a plan falls below an entrepreneur's average entrepreneurial profits (i.e. aspiration), this plan will not be used.

3.4 An Entrepreneur's Behavioral Rules and Interaction Rules (BRIR)

In describing the rule-following and rule-generating aspects of alert entrepreneurship, these behaviors are based on an entrepreneur's choice of behavioral and interaction rules (BRIR).

These rules are heuristics that generate different combinations of input use and thus capital plans. Hence, it is these rules that generate the types of input choices used in the perceived production function. These rules are highly interdependent activities. The interaction rules define an entrepreneur’s social network of strong and/or weak information ties. This social network determines "who" an entrepreneur interacts with such that it provides for the transmission of knowledge of those choices of plans made by members of an entrepreneur's social network. While, an entrepreneur's behavioral rule takes into account the plan choices made by its social network members so as to generate its own combinations of input use. Both rules jointly aid in the entrepreneur's construction of plans. Table 2 summarizes the five pairs of behavioral and interaction rules where the first two pairs and last three pairs are categorized as rule-following and rule-generating behaviors respectively.

Table 2: An Entrepreneur's Behavioral and Interaction Rule Choices

Rule-following Behavioral Rules	**Corresponding Interaction Rule**
1) Imitate the most profitable plan among one's product-market group.	1) Interact only with those entrepreneurs in the same product-market group and thus leads to the formation of Strong information ties.
2) Copy and revise upon the most profitable entrepreneur among one's product-market group (i.e. "self-correcting role of entrepreneurial alertness" (Kirzner, 1979, 1997a,b)).	1) Interact only with those entrepreneurs in the same product-market group and thus leads to the formation of strong information ties.
Rule-generating Behavioral Rules	**Corresponding Interaction Rules**
3) Adopt one innovative input[14] from the most profitable entrepreneur in one's social network.	2) "Innovating interaction rule": Interact with entrepreneurs in any product-market and thus leads to the formation of weak information ties
4) Choose the first innovative input that one has not used before.	No social interactions (entrepreneurial imagination).
5) Recombine an entrepreneur's existing use of input combinations with the plan choice of the most profitable entrepreneur in one's social network.	2) "Innovating interaction rule": Interact with entrepreneurs in any product-market and thus leads to the formation of weak information ties

3.4.1 Rule Following and Rule Geneation

The distinction between rule-following and rule-generating behavior is based on the extent to which new production experiences and thus, innovative plans are developed within the social system. Specifically, so long as plans are consistent with an entrepreneur's past experience, rule-following behavior is characterized by the diffusion of *existing* plan choices. The diffusion of plan choices and subsequent diffusion of production experiences have a

14 An innovative input refers to the last four input uses of a plan. The model is initialized where all agents do not employ this input. An un-established input use is used to reflect innovative inputs.

tendency to reduce the heterogeneity of plans in a market. This reduces the extent of experimentation of plans and, therefore, rule-following behavior generates negative feedback or equilibrating tendencies resulting in a highly stable/orderly market (Ng, 2001). While, rule-generating behavior is marked by the absence of the constraining influences of past production experiences and, therefore, involves the creation and adoption of innovative plans. The creation and adoption of new plans increases the heterogeneity of plans in the market. The creation of heterogeneous plans provides conditions for further experimentation to which a positive feedback of increasingly diverse innovative plans can arise. This diversity of innovative capital plans creates "far from equilibrium" (Jantsch, 1980; Marion, 1999; Prigonine and Stengers, 1984; Stacey, 1992, 1995) conditions to which this yields the onset of bifurcation or structural change in markets (Ng, 2001).

3.5 Product-Market Choice

In addition to being alert to profitable plan choices, an entrepreneur also exhibits an alertness to profit opportunities along the product-market dimension. This product market choice is influence by two factors: 1) the profitability of past product-market choices and 2) exiting input choices. In drawing on past experience, entrepreneurs have a greater propensity to choose those product-markets that have earned the highest profits. By taking the maximum value of the market change probability function, $MCP_{s,k}(i_t^*)$, as shown in equation 1, among all product-market entered, an entrepreneur's choice of product-market is made. In addition, an entrepreneur's choice of product-market is also influenced by his current choice of inputs, X^*_t. That is, the greater extent to which an entrepreneur uses inputs that are specific to a given product market, the greater propensity to choose that product market[15]. This augments the value of the $MCP_{s,k}(i_t^*)$ and thus impacts the entrepreneur's choice of the product market. By accounting for these factors, the agent utilizes his knowledge/memory of plan choice to influence his choice of product-market.

3.6 Alertness/Aspiration Behavioral Conditions

Given the decision processes that govern the entrepreneur's choice of plan, BRIR and product-market, these choices are conducted when the entrepreneur satisfies two behavioral conditions. Condition 1 relates to the entrepreneur's choice of plan and BRIR. It states that an entrepreneur conducts a plan specified by its BRIR choice only if its current profits fall short of his aspiration condition. This is shown with condition 1.

Condition 1

$$\Pi_{s,k,t}(X_t \mid i_t^*, cp_t) < Asp_{s,k}(i_t^*) \qquad \forall s,k,t$$

With this condition (1), an entrepreneur with greater alertness and thus, aspirations, has a greater tendency to conduct changes in one's plans and BRIR. This allows for greater expression of alertness to opportunities in the market.

Condition 2 relates to an entrepreneur's product-market choice. It includes the first condition (condition 1) as well as a second condition (condition 2). This second condition reflects a financial feasibility criterion that specifies an entrepreneur can only conduct a product-market choice only if its cumulative profits exceed the cost of changing to that product-market. The cost of product-market change is to reflect the transaction cost associated with such changes. These include the cost of redeploying new assets that are specific to the product market in

15 For instance, commodity product market utilizes inputs that are oriented towards developing scale economies.

question. These product market costs are specified as parameters. The following shows the behavioral conditions associated with this product-market choice.

Condition 2

$$\Pi_{s,k,t}(X_t \mid i_t^*, cp_t) < Asp_{s,k}(i_t^*) \qquad \forall s,k,t$$

$$Cumul.Entrep.\Pr ofit_{s,k} = \sum_{t=1}^{T}\sum_{i}\sum_{cp}\Pi_{s,k,t}(X_t \mid i_t^*, cp_t) > Cost\,of\ \ product\ market\ change \quad \forall s,k$$

<u>3.7 Simulated Market Environment: Agricultural Supply Chain</u>

Given the entrepreneurial behavior of agents, these agents are populated with in a simulated agricultural supply chain market environment. In characterizing this simulated market environment, the information structure of the agricultural supply chain plays an important role to the behavior of the alert and subjective entrepreneurs. Since alert entrepreneurship stems from asymmetric knowledge advantages (Jacobson, 1992), the structure at which information is disseminated impacts the extent to which entrepreneurs can “grasp” for such market opportunities. Information is defined with respect to two alternative market coordinative mechanisms: market prices such as in commodity markets and contractual arrangements that contains market prices with adjustments for pricing premiums.

The environment in which subjective and alert agents populate is defined by a supply chain structure shown in appendix 1. Appendix 1 shows an end-user market connected to three supply stages -processor, farmer and life science- where each supply stage contains three product-markets –commodity (Comm.), Vertical Coordination 1 (VC1), and Vertical Coordination 2 (VC2). End user demands for each product market are determined exogenously by a set of parameters where end-user prices are then determined by an excess supply/demand function at the processor stage[16]. The commodity product market currently reflects the dominant means to which agricultural products are marketed and produced. That is, market prices are solely used to coordinate the activities in this supply chain. Market prices at each supply stage determine the production decisions of entrepreneurs at each stage to which their choices impact the prices confronted by other stages. This is depicted by output ($P_{s,t}$ ($\eta_{s,t}$ |i^*_t)) and ($R_{s,x,t}$ (i^*_t)) input price transmissions between the adjacent supply stages. The black downward pointing arrows and upward dashed arrows in appendix 1 shows this transmission of prices. Hence in this commodity product market, market prices are used to coordinate each adjacent supply stage.

On the other hand, as contractual arrangements are increasingly utilized in agriculture (Boehlje, 1995,1999; Martinez, 1999), VC1 and VC2 depict an alternative information structure where market prices and price premiums are utilized to coordinate the production and marketing of the entire supply chain. The distinction between the VC1 and VC2 market arrangements is differences in the specification of price premiums[17]. One of the advantages conferred by the use of contractual arrangements is its greater ability to transmit end user demands through out the supply chain. That is, the price faced by the processor stage is communicated to all supply stages to which this provides entrepreneurs in each supply chain a greater responsiveness to end user demands. Hence, relative to the commodity product market, this enables the greater coordination of activities of the entire supply chain. As a result, in the VC1 and VC2 product markets, the information structure is defined by not only the presence of price premium, but also the dissemination of end user information to each of the supply stages. This is shown in appendix 1 with the thin arrows that connect the end-user demands with each stage of the supply chain.

16 This price formulation has a similar functional form as prices in other stages of the supply chain.
17 For detailed discussion of the derivation of the price premium structures used in VC1 and VC2 see Ng (2001).

3.7.1 Price Premiums

Since price premiums as well as price are used to coordinate agricultural products in the supply chain, these premiums need to be defined. Price premiums are used to reflect the additional value inherent in VC agricultural products (i.e. IP soybean seed, soybeans, processed soybeans). Price premiums are based on the end users valuation of goods produced in the processor stage. These premiums are calculated with equation 10.

Equation 10

$$\text{Price Premium}^*_{s,t}(i^*_t) = \beta_{s,t}(i^*_t)\ \text{Price}^*_{processor,t}(\eta_{processor,t} \mid i^*_t)$$
$$\forall\, i = VC1 \text{ or } VC2,\ t,\ s = Farmer, Life\ science\ stage$$

These price premiums are calculated by taking the product of a premium proportion, $\beta_{s,t}$ (i^*_t), for an upstream stage s, and the output price of the processor stage, $\text{Price}^*_{processor,t}(\eta_{processor,t}|i^*_t)$, for each vertically coordinated arrangement. This premium proportion is a matrix defined for each supply stage for each of the VC1 and VC2 product groups where differences in value are used to distinguish VC1 and VC2. The premium proportion, $\beta_{s,t}$ (i^*_t) determines the proportion of rent sharing between adjacent supply stages. For instance, a large value of this premium proportion for the farmer supply stage indicates that farmers receive a greater share of the rents in the supply chain structure. Given this price premium, to incent the upstream stages, farmer (F) and life sciences (L) stages, s, to produce VC products, this price premium, Price $\text{premium}^*_{s,t}$ (i^*_t), is rewarded to each of these upstream stages, s, by the adjacent downstream stage. For instance, the farmer stage receives its price premium from the processor to incent the production of VC primary agricultural products (i.e. IP soybeans) and in turn the farmer stage incents the life science stage with premiums for the production of VC inputs (i.e. IP or genetically modified soybean seed). The processor does not directly receive a premium. Rather, it is the residual claimant in the supply chain. Given this structure of premium payments by adjacent supply stages, these premium proportions, $\beta_{s,t}$ (i^*_t), are placed in their respective positions in appendix 1.

Based on these price premiums, the farmer and life science stages are rewarded with prices determined by the excess demand/excess supply conditions of that stage with the addition of these price premium values. Equation 11 yields the vertical coordinated output prices, $VCPrice^*_{s,t}$ ($\eta_{s,t}$ |i^*_t), received by the farmer and life science stages.

Equation 11

$$VC\,Price^*_{s,t}(h_{s,t} \mid i^*_t) = Price\,Premium^*_{s,t}(i^*_t) + Price^*_{s,t}(h_{s,t} \mid i^*_t)$$

$$\forall s = Farmer, Lifesciences,\ i = VC1 \text{ or } VC2,\ t$$

As these price premiums are made available to the farmer and life science stage, this greater transmission of pricing information corrects for the decision errors that can be made between supply stages. As a result, an improvement in the quality of information in terms of greater incentives and reduced error should improve the coordination of markets. With respect to appendix 1, this transmission of pricing information as a price premium to each supply stage is shown by the arrows that connect the end-user demand to the farmer and life science stages.

Another distinction made between commodity and VC product-markets is the lower subjectivity among agents. With a contractual arrangement, the terms of agreement, such as the value of price premiums, are well specified. This circumvents an entrepreneur's subjectivity. Consequently, relative to commodity product markets, VC product-markets have a lower subjectivity parameter, $\sigma_{s,k,t}^{subj}(i^*_t)$. In addition, since VC1 and VC2 are both contractual arrangements that differ only in their rent sharing proportions, $\beta_{s,t}$ (i^*_t) then both VC product markets have the same subjectivity.

3.7.2 Summary of Product-Market Differences

Based on the differences in information quality between these alternative product-markets, table 3 highlights their differences.

Table 3: Product-Market Differences

Product-Market	**Vertical Info. Structure**	**Extent of Subjectivity** $\sigma_{s,k,t}^{subj}(i^*_t)$	**Price Premium** $\beta_{s,t}(i^*_t)$ **s=VC1 or VC2**
Commodity	Output/input prices transmitted between adjacent stages	High = 0.3	None
VC1	Output/input prices transmitted between adjacent stages + Price Premium	Low = 0.1	Farmer stage=0.25 Life sciences stage=0.15
VC2	Output/input prices transmitted between adjacent stages + Price Premium	Low = 0.1	Farmer stage=0.10 Life sciences stage=0.10

With these parameters, VC1 represents a contractual arrangement with a high price premium and rent sharing occurs. In VC1, a farmer receives 25% price premium from the processor. The life science firm receives a 15% price premium from the farmer. As a result, relative to VC2, VC1 reflects a high premium and rent sharing contractual arrangement. One expects that such an arrangement provides an equitable incentive for farmers and life science entrepreneurs to exploit opportunities availed from VC1. While on the other hand, VC2 represents a low premium and no rent sharing contractual arrangement. In VC2, farmers receive a price premium of 10% from the processor. However, this price premium is in turn paid to the life science stage. Hence, in this contractual arrangement, the farmer effectively earns no price premium and, therefore, exhibits no rent sharing and the life science firm earns a lower price premium of 10%. This specification was made so that one can determine if information transmission, independent of premium incentives, confers advantages from supply chain coordination.

4.0 Results and Discussions

4.1 Population of Entrepreneurs: Expression of Complex and Unpredictable Behavior

Using the Mathemetica programming language, an agent-based simulation model was created. In defining the parameters of this model, the simulation has a time horizon of 300 time steps. Each supply stage is populated by 40 agents with a total of 120 agents[18] among all three supply stages. In particular, with in each supply stage, the population has an initial distribution of 80% (32 agents), 10% (4 agents) and 10% (4 agents) of commodity, VC1 and VC2 entrepreneurs, respectively. These initial population distributions are used to reflect the current dominance of the commodity type product-market arrangement (Ng, 2001). Based on these and other[19] parameters, figures 1, 2, and 3 show the population of entrepreneurs in each of the three product-markets for each stage of supply chain for a single simulation run. The red, green and blue lines depict the population trajectories for the commodity, VC1 and VC2 product-market groups respectively.

18 3 stages*40 agent/stage=120
19 Due to space constrains, a discussion of other parameters are made in Ng (2001)

Figure 1

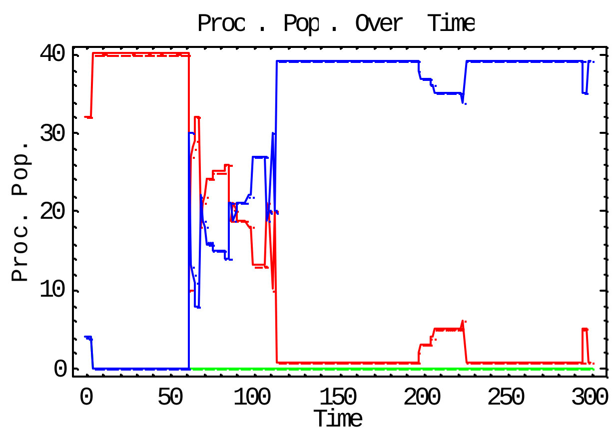


Figure 2

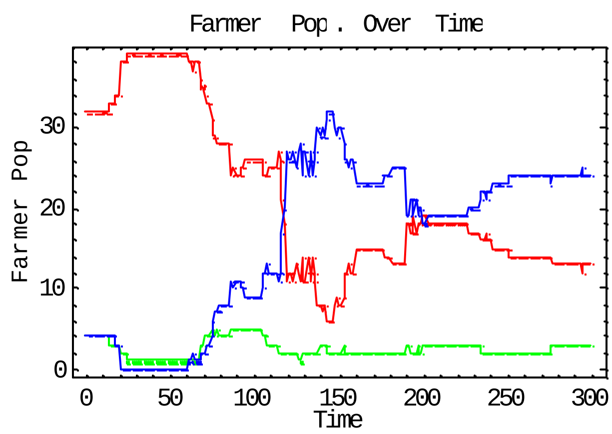
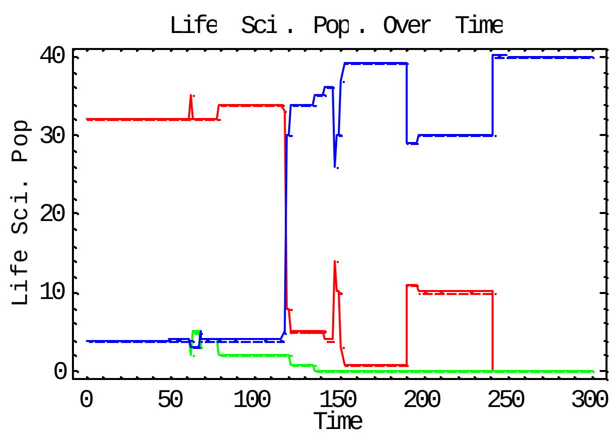


Figure 3



4.2 Complex Population Behavior

A common pattern found among these population trajectories is the cyclical expression of order and chaos. As shown in figure 1 (processor stage), 2 (farmer stage), and 3 (life science stage), all supply stages witness an initial period of a highly stable population of commodity type entrepreneurs (red line). At least 80% of the population (32 out of a total 40 entrepreneur) in each supply stage remains in this commodity product-market. This stability confers a high degree of market order. This market order is attributed to rule-following behaviors[20] that lead to a convergence of a plan configuration that yields a stable market order.

However, the stability of this market order is perturbed by a radical or bifurcated change in the population. This is witnessed in simulation periods 61,117 and 118 for the processor, farmer and life science stage respectively. In such an event, positive feedback influences amplify the unpredictable behavior of the alert entrepreneur causing a large structural change in the population of agents in the commodity product market (Ng, 2001). This is marked by the sharp changes in population trajectories at these periods. In following such an event is a period of chaos or disorder. In this chaotic period, one observes a marked increase in the fluctuation of the population. This is particularly evident for the processor and farmer stages during the periods 61-115 and 117-150 for these stages respectively. This fluctuation is attributed to the positive feedback influences that amplify the unpredictable behaviors of alert entrepreneurship[21]. In particular, individual action can aggravate large structural changes in the population of agents. In a market previously dominated by a commodity arrangement, a small number of agents were sufficient to cause a dramatic reorientation in the market structure. As alert entrepreneurs were

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20 In the commodity product-market group, entrepreneurs in all supply stage show that at least 85% of all BRIR reside in the rule-following category.

active in experimenting with innovative capital plans, successful capital plans were revealed in the VC2 product-market. These successful capital plans depicted in terms of high profit lead to a positive feedback or band-wagon effects. Other alert entrepreneurs in observing the success of innovative capital plans copied or revised (BRIR 1 and 2) these successful capital plans. This diffusion of capital plans leads to the further adoption by other entrepreneurs to which through this positive feedback effect, a structural change or bifurcation to the VC2 product market occurred.

4.2.1 Direction of Bifurcated/Structural Change

Although positive feedback explains the process of the bifurcation event observed in figures 1,2 & 3, it does not explain its direction. The incentives availed in the different product-market arrangements also play a guiding influence in the direction of this bifurcation. Given the initial conditions of the simulation run[22], in the processor stage, the bifurcation to the VC2 product market occurred, because this contractual arrangement minimizes the premiums paid to the farmer. That is, a processor faces a price premium of 10% under VC2 as oppose 25% in VC1. As a result, processing firms have a cost minimizing incentive to choose the VC2 arrangement over VC1. In spite of the higher price premium in the VC1 product market, the direction of product-market bifurcation at the farmer stage is also towards VC2. This is an important finding. For this simulation, farmers are not responsive to price premiums in VC1 and this subsequently implies that rent sharing arrangements may not matter in determining the direction of product market change. As a result, an increasing value of price premiums and an

21 Stated otherwise, this is the amplification of the stochastic idiosyncratic behaviors of micro-entities.
22 Initial conditions are dictated by a set of parameters explained in Ng (2001), but they also include a random seed value that initializes values for the initial levels of capital endowment, aspirations levels.

equitable rent sharing scheme represented by VC1 does not appear to influence a farmer's choice of product market.

Although this result appears to be counterintuitive, the reason is the alert farmer is responsive to not just price premiums, but is responsive to other supply chain factors that influence its entrepreneurial rents. That is to say, farmers are first and foremost alert to entrepreneurial rent opportunities of which price premiums are only one factor. The farmer's choice of VC2 arises because it accounts for those product-market choices made in the downstream and upstream supply stage. In the downstream stage, processors predominantly chose the VC2 product-market group. Through a "supply stage effect", choices at the downstream stage –processor- conditions the opportunities for the farmer stage in terms of increasing prices. To elaborate on this supply stage effect, a processor's choice of VC2 product-market group creates high input demands for VC2 products (i.e. soybeans) in the farmer stage. This influences the incentives to enter the VC2 product market. As market demands are increasing, these greater incentives, thereby, motivate farmers to enter this market. Therefore, in spite of an absence of premiums, through high output prices, the supply stage effect emanating from the processor stage conditions the incentives for farmers to enter the VC2 product market.

Similarly, in the life science stage, its choice of VC2 also conditions the opportunities in the farmer stage through lower input prices for VC2 inputs (i.e. soybean seed). The production of VC2 inputs (i.e. soybean seed) by the life science stage reduces the input prices faced by the farmer. As a result, the VC2 choices in the downstream (processor) and upstream (life science) stages condition the opportunities for the farmer stage such that greater entrepreneurial rent is afforded from choosing the price premium schedules of the VC2 product market rather than the high premium and rent sharing arrangements of VC1. Therefore, in the farmer stage, the absence of price premiums and sharing of rents in this stage does not appear to influence the direction of product-market bifurcation in this stage.

With respect to the life science stage, even though higher price premiums could have been earned by choosing the VC1 product-market group, the direction of bifurcation at this supply stage is also towards the VC2 product-market group. For reasons similar to the farmer stage, the choices of downstream stages (i.e. processors and farmers' choice of VC2) condition the entrepreneurial rents in the life science stage. That is, the entrepreneurial rents arising from those supply stage effects of the farmer and processor stage exceed the gain in price premiums (5% increase) of a VC1 product-market arrangement. For reasons of minimizing price premium costs, the processor's choice of the VC2 product-market conditions the entrepreneurial rent opportunities availed for the farmer stage whose choice of the VC2 product-market, in turn, influences the demand of VC2 inputs (i.e. soybean seed) in the life science stages. This sequence of inter-supply stage choices or supply stage effects lead to an increasing trend in output prices for the life science stage[23]. Therefore, due to these supply stage effects, the direction of product-market bifurcation is in the direction of VC2 arrangement. To conclude, due to these supply stage effects, the output prices in the VC2 product market as well as the greater demand for VC2 inputs (i.e. soybean seed) provide greater entrepreneurial rent in choosing the price premium schedules of the VC2 product market than the high premium and rent sharing arrangements of VC1. Like the farmer stage, the increased price premiums of the VC1 product market does not appear to influence the direction of product-market bifurcation in the life science stage.

4.2.2 Self-Organization

In addition to this bifurcated behavior, another expression of complex systems is the capacity for self-organization. As one observes in simulation periods 86-112, 135-200 and 141-161 for the processor, farmer and life science stage respectively, an emergence of a new market order arises from chaos. In following the bifurcation event and chaotic periods, the VC2 product-market emerged to replace the commodity market as the dominant product-market group.

This process of self-organization is unique to the complex behavior of agent-based methods. Using an agent-based approach to study this process of self-organization is important, because it provides insight on the dynamics that lead a system to quasi-equilibrium outcomes. The use of agent-based model to study the self-organizing processes introduces an important temporal dynamic to explain for the emergence of equilibria or quasi-equilibrium outcomes[24].

From this simulation, one of the conclusions drawn is: given supply stage effects, price premiums are important in influencing the direction of product-market bifurcation, as seen in the choices of VC2 product-market, but the amount of price premiums and rent sharing arrangement need not be a decisive factor in determining its direction. This resonates a complexity theme as well as Hayek's libertarian view (Fleetwood, 1995; Hayek, 1948) in which acts of social engineering will produce unexpected consequences. That is to say, the determination of an "optimal" premium and rent sharing schedule need not yield desired changes in markets. That is, price premiums only bring about conditions to stimulate alert behavior, but not govern entrepreneurial choice. It is for this reason, price premiums and rent sharing arrangements are important in so far as stimulating alert behavior, but there values need not determine the

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23 This is shown in Ng (2001).

direction of agricultural structural change. This is because entrepreneurs are alert to other opportunities in the market environment of which price premiums are only one component. An agent's subjectivity, alertness, knowledge of past capital plan choices, input and output prices are all taken into account in forming the agents perception of market opportunities.

4.3 Sensitive Dependence of Agricultural Markets

Since the agent's perception of market opportunities are subjective and therefore unpredictable and given the sensitive dependent nature of complex systems, the unique history of each agricultural market yield very different evolutionary trajectories. In that, the previous simulation runs reflect only one unique historical trajectory of agricultural market structural change. For slight differences in the initial conditions of each simulation run will very different structural change processes. As a result to demonstrate this sensitive dependence, simulation runs that differed in the initial conditions were conducted. The initial "random seed" used in the simulation were changed while keeping all other parameters unchanged. A "random seed" initializes the initial capital endowment of each agent and their aspiration levels. Even though each agent has a different endowment of capital and aspiration level, the distribution of capital endowment and aspirations remains the same. These changes in the "random seed" were made to reflect differences in initial conditions to determine the sensitivity of market evolutionary trajectories from these changes. In changing these "random seed" values, one observed dramatic differences in the evolutionary trajectory of markets[25]. They differed in both the direction of bifurcation, the magnitude of change, and timing and duration of such changes. In addition, one also conducted small variations in parameters of the simulation model (i.e. changing the

24 One should note the use of an "attractor" metaphor would be more appropriate in describing the convergent tendencies of a system that does not reach an equilibrium point

population distribution of agents by 1 agent independently for each supply stage (the processor, farmer, life science stage), increasing premiums by 1% and aspiration by 1% independently for each stage) while holding the "random seed value" unchanged. This also yields highly divergent directories.

These observations demonstrate the sensitive dependent nature of agricultural supply chain systems. The implication of this is that structural changes will be different for each industry. The structural change processes for each agricultural product will be unique to its "initial conditions" of the market and the initial and subsequent choices of the subjective and alert entrepreneur. More over, the sensitive dependence property also highlights an important premise that the individual actions of an alert and subjective entrepreneur can create large though infrequent changes in the structure of an industry. Hence, rather than attribute such large changes to exogenous influences, such changes are endogenously driven and can be catalyzed by the efforts of a single entrepreneur.

However, this is not to say that, that there are no general patterns or tendencies observed in the changing face of agriculture, it is only that the exact details of that change will necessarily differ. This is akin to the complexity notion of an "attractor" (Kauffman, 1993, 1995) where complex systems do exhibit general patterns of behavior, but the details of a given trajectory will necessarily differ. These general tendencies or patterns of market structural change are examined from a type of Monte Carlo simulation approach.

4.4 Direction of Product-Market Bifurcation/Structural Change: Monte Carlo Simulations

Through a Monte-Carlo approach, one can observe general tendencies in the behavior of structural change in an agricultural market. Although one cannot observe the dramatic structural

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he diverse combinations used to conduct these different simulation runs, these results are not reported.

changes that were seen in the individual simulation run, the average changes in population from such an approach can indicate the potential "tendencies" for the system to “gravitate” to particular product markets.

With a Monte-Carlo approach, an experiment was conducted by consecutively increasing the price premiums at 10% increments of the VC1 product group[26] and then observations were made on the population trajectories associated with each increment. Specifically, for each 10% premium increment, a Monte-Carlo simulation containing 35 iterations of individual simulation runs which differed only in their random seed value was run. Population distributions remain the same where the commodity product market contains 32 agents (80%), VC1 contains 4 agents (10%) and VC2 contains 4 agents (10%).

Figure 4 shows the results of these Monte-Carlo Simulations. For reference purposes, appendix 2 shows the Monte-Carlo simulation results for the population trajectories for each supply stage over time. These results are based on changes in the random seed values for the 35 individual runs with no changes in the VC1 premium. This is termed the base case scenario.

26 VC1 has a price premium proportion of 25% and 15% for the farmer and life science firms, respectively. The 100% increments are based on this “base” premium value.

Figure 4: Base Case Monte-Carlo Simulation Results

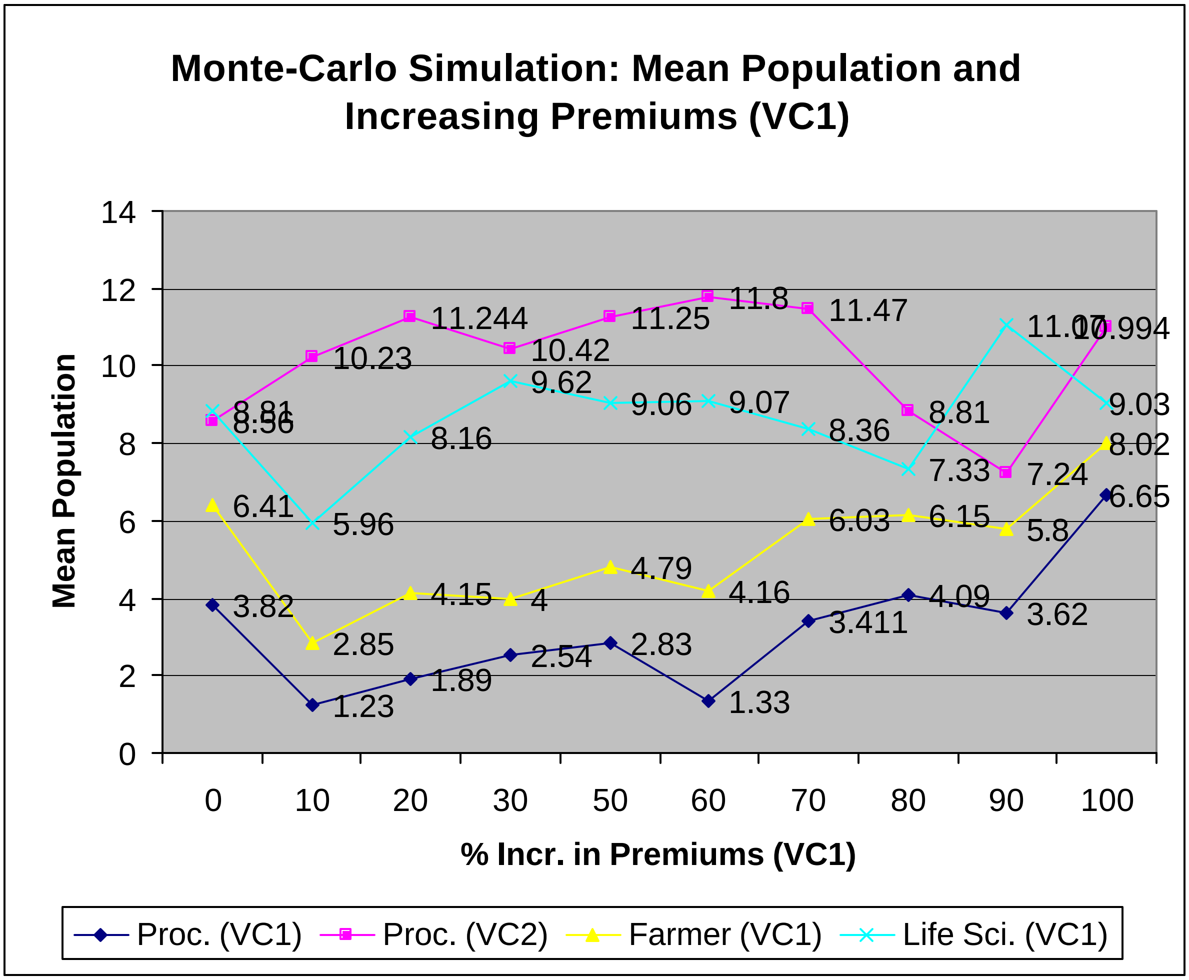

Figure 4 shows that increasing premiums in the VC1 product group did not appreciably increase the "average" population of agents in these groups. Given an initial population of 4 agents in each supply stage for the VC1 product market, a 100% increase in premiums for the farmer from 0.25 to 0.5 and for the life science firm from 0.15 to 0.3 resulted in an increase in population to 8.02 agents for the farmer stage and 9.03 agents for the life science. Although one cannot accurately predict the entrepreneur's responsiveness to such increases in premiums, one expects a much larger increase in the population of this product-market group. In calculating the

% change in population from this 100% increase in premium, the difference in VC1 population at the 100% increase in premium from the base case (0% increase) is made as a ratio of the combined average population of Commodity and VC2 groups in the base case (0% increase)[27]. This serves as an approximation of the responsiveness of other entrepreneurs in the VC2 and commodity groups in exploiting the higher premium of the VC1 product market. For the farmer and life science stage, this percentage change is 4.79% and 0.705%, respectively. Given the 100% increase in premium, this decline in the population of the commodity and VC2 product-market group is small and thus suggests that increases in the premium of VC1 do not provide large incentives for entrepreneurs in these groups to enter the higher premium product-market.

With respect to firms in the processor stage of the VC1 group, one observed a somewhat declining population for ranges between 0 to 70% increases in premiums. This, however, is expected as premiums are paid by the adjacent downstream stage (processor) and therefore increases in the premium of VC1 incur a greater premium "cost" to these processors. This lead to an exit of processor firms to enter the VC2 group where premiums are at a smaller rate of 10%. Hence, from figure 4, one observes a larger population of VC2 (mean population of 10.49 agents) processors relative to VC1 processors. As a result, in response to increasing premiums in VC1, processor entrepreneur's who enter VC2 confer gains in the form of cost reductions relative to the increasing premiums of VC1. Therefore, there was a significant "initial" change in the population at the 0.0% (base case) increase in VC1 premium of 4.56 from the initial level of 4.0 entrepreneurs. This increase is attributed to the exit of commodity entrepreneurs in the

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27 Since all increases in population for the VC2 arises from decreases in the population from Commodity and VC1 groups, we take the sum of these two groups. This is because there is no influx of population and thus all increases in the population of VC1 must arise from decreases in population of the other groups to which this serves to depict

processor stage who are exploiting benefits from VC coordinated arrangements but could not bear the higher costs incurred by VC1 and therefore led to the large increase in population. However, for increasing premiums beyond the base case (0% increase in premium), it appears that the increase in the premiums of VC1 does not demonstrate significant response to increases in population of VC2. That is, in so far as large population was observed, there does not appear to be any significant positive relationship between increasing premiums in VC1 and the entrance of entrepreneurs to VC2 product group. Over the range of increase in premiums (10-100%), the population response is relatively constant and therefore increasing premiums do not appear to influence the population of VC2 groups. In addition, calculated in the similar fashion as the farmer and life science stage, the % change in population with respect to increases in the population of VC2 from commodity and VC1 product markets was 7.74%. Again like the farmer and life science stage, increasing the premiums of VC1which effectively renders VC2 more attractive does not appear to significantly incent entrepreneurs in the commodity and VC1 group to enter VC2. Hence, this general pattern of behavior is suggestive that increasing premiums may not cause expected structural change. There a number of factors that restrain the extent to which this change can occur and these are discussed as follows:

4.5 Supply Stage effects

From both the individual and Monte-Carlo simulations, they demonstrate that supply stage effects need to be jointly considered with price premiums in determining the direction of product-market bifurcation. Price premiums and rent sharing arrangements are important in so far as stimulating alert behavior, but the magnitude of these values as demonstrated in the

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these groups' responsiveness to the higher premiums in VC1. A similar calculation is done for the processor stage, except that VC1 and VC2 are interchanged.

Monte-Carlo experiments show that they need not determine the direction of product- market change. This is because entrepreneurs are alert to other opportunities in the market environment of which price premiums are only one component, as this was suggested in the individual simulation run. In particular, an agent's subjectivity, alertness, knowledge of past capital plan choices, input and output prices are used to take into account the decisions made by entrepreneurs in other stages of the supply chain. As a result, an agent has a "greater awareness" of not only the opportunities and constrains availed in its supply stage but also its adjacent stages. That is to say, since the capital plan and product market choices of entrepreneurs in a supply stage are interrelated through input and output prices, the choices made by entrepreneurs in any given stage impacts the entrepreneurial choices of other stages of the supply chain. As a result, even though price premiums and rent sharing arrangements can stimulate "alert" entrepreneurial behavior, supply stage effect can also influence their choices. This was evidenced in the individual simulation run.

However as these supply stage influences are subject to the "sensitive dependence" property of complex systems, choices made at one stage of the supply chain can dictate choices made by the entire chain. Since entrepreneurial choices are unpredictable, the nature of these "supply stage effects" is sensitive dependent to their choices and, therefore, changes in product market are increasingly uncertain. These "supply stage" effects may influence the direction of product-market bifurcation in a direction that differs from the "expected" change availed from increases in price premiums. In fact, the absence of significant adjustments in the population from elevating premiums in the Monte-Carlo simulations suggests that these supply stage effects may curtail the extent of the movement in population necessary to create structural change in product markets.

Consequently, both supply side effects and the premium schedules of a contractual arrangement need to be jointly considered in which the relative magnitude of these influences are dependent upon the initial conditions of the market. Thus, offering increased premiums with out considering the complex interaction between supply stages can create unintended consequences. From a maximizing of societal welfare point of view, these unintended consequences can lead to a distribution of total rents in a system that differ from those specified in a contractual arrangement. Hence, the formation of a "best" contract should involve specifications that account for supply stage effects as well as sufficient premiums to incent alert behavior.

4.6 Entrepreneurial Experience

Another factor that constrains the extent of product-market bifurcation is the accumulation of entrepreneurial experience can render “organizational inertial” (Hannan and Freeman, 1984) tendencies. Through trial and error experimentation, entrepreneurs acquire experience of successful and non-successful plans where initial choices that give rise to successful plans can contribute to path dependent behavior. This has a tendency to constrain the extent of entrepreneurial alertness, as entrepreneurs will have a “preference” to reinforce past behavior. Subsequently, this leads to a reduction in the experimentation efforts of entrepreneurs to explore other product markets. Thus, this reduces tendencies for the system to be subject to a product-market bifurcation.

4.7 Population Distribution

The initial population distribution of entrepreneurs is biased towards the commodity product market to which there are “inertial” tendencies that restrict the movement of entrepreneurs to other product markets. The “initial population” distribution of the simulation runs has 80% of the population residing in the commodity product market with 10%

in each of the VC1 and VC2 product markets. The larger population proportion of entrepreneurs in the commodity product-market creates similar inertial tendencies as the historical influences acquired from entrepreneurial experience. However, these inertial tendencies are motivated by a different reason. The larger population facilitates greater trial and error experimentation such that the diversity of entrepreneurial knowledge/experiences (i.e. capital plan choices) is given expression. This accelerates the market discovery process (Hayek, 1978) in revealing successful capital plans. As successful plans are revealed, they become adopted or imitated through copy and revise behavioral and interaction rules (BRIR 1&2). The imitation of these successful plans over a larger commodity population implicates that these plans can become quickly adopted to be an institutionalized norm of behavior (Scott, 1995). As these successful capital plans become diffused, they become institutionalized with in the entrepreneur's production experience to become an accepted "norm of behavior".

Such conformance to institutionalized norms is evidenced by the extent of rule following behavior expressed by entrepreneurs. This extent of rule following behavior is measured by the sum of the proportion[28] of the rule following behavioral and interaction rules (BRIR1 & 2) to all rules chosen by the entrepreneur (BRIR, 1,2,3,4, & 5). Values closer to 1.0 depict high rule conformance and values closer to 0 depict rule generation (non conformance). The "average" value of this proportion is then calculated among all entrepreneurs with in a given product market. Based on a Monte-Carlo simulation of 35 runs with no increases in premium (i.e. base case), table 4 shows these values for the different stages of the supply chain in the commodity product market for periods 1 to 300.

28 This proportion is defined as the sum of the number of times an agent a given product market that have chosen BRIR 1,2 &3 divided by the sum of the number of times an agent in a given product have chosen all BRIR.

Table 4: The Proportion of Behavioral and Interaction rules among Entrepreneurs in all Stages

Supply Stage	**Average Proportion of Rule following BRIR**
Processor	0.757
Farmer	0.968
Life Science	0.769

In light of the higher population of commodity entrepreneurs, the proportion of BRIR in table 4 demonstrate in all stages, entrepreneurs have in an excess of 75% probability of exhibiting rule following or rule conformance behavior. This demonstrates that population influences contribute to increase rule conformance. As a result, the “top-down” pressures for institutional conformance serves to create inertial tendencies among entrepreneurs in the commodity product group to which this yields resistance toward product-market bifurcation. This is a pattern of behavior that is consistent with organizational ecology and institutional theories (DiMaggio and Powell, 1983; Scott, 1995; Hannan and Freeman, 1977).

5.0 Conclusion and Discussions

As the utility of agent-based models stem from its semi-inductive approach (Axelrod, 1997), one of the important insights of this agent-based exercise is it brings to bear the fundamental unpredictability of complex system behavior. Due to the sensitive dependence property of complex systems, the initial and subsequent sequence of choices made by alert and subjective entrepreneurs yields highly divergent and therefore unpredictable future trajectories. The implications of this property of complex systems to the study of structural change in agricultural markets is that an entrepreneur’s initial choice can have significant impacts in restructuring agricultural markets. That is to say, individual processors, farmers and life science firms can make decisions that impact not only their immediate supply stage, but also the entire supply chain. Simply put with sensitive dependence, although not frequently, individuals do matter in influencing the future trajectory of the industry in a matter.

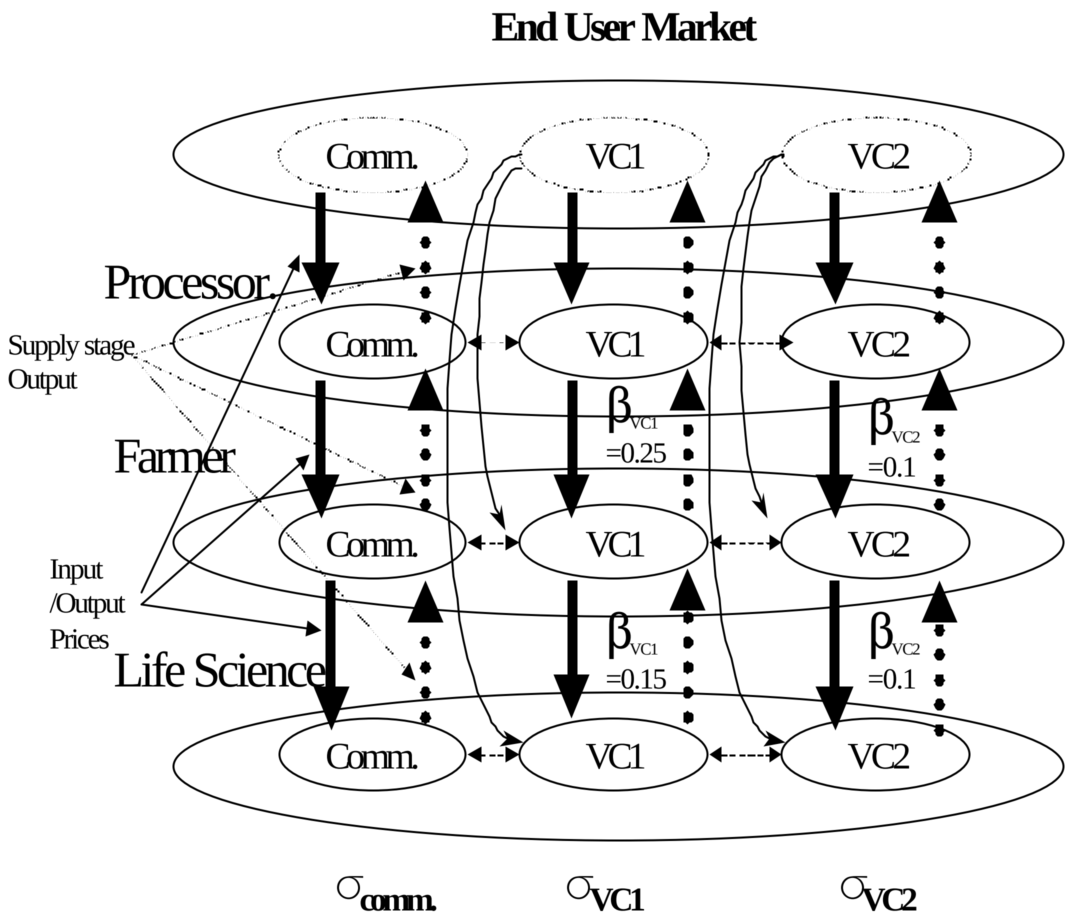
Another related point is: since agricultural structural change processes are unique to the sequence of initial and subsequent choices made by entrepreneurs, changes in one market (i.e. broiler industry) are not "replicable" to other markets. This has implications to the generalizability of previous research in the study of structural change of agricultural markets.

However, this is not to say, the evolution of each agricultural market is completely idiosyncratic to the endogenous processes of the system, but rather structural change processes do exhibit generalizable patterns of behavior. It is the details of that pattern that differ. In particular, as shown through the Monte-Carlo simulation experiments, one pattern of behavior is the lack of significant response of product-market bifurcation to increasing premiums in VC1 arrangements.

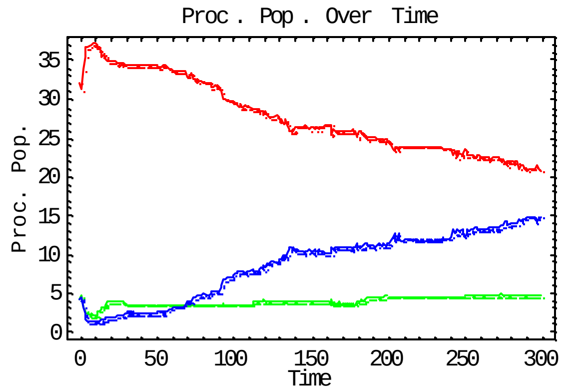
In conclusion, the insights from this agent-based modeling exercise demonstrate the utility of its semi-inductive approach to agricultural structural change research. However with respect to the development of complexity science perspective in social science research, with the aid of agent-based models, these models provide an important tool for the development of further understanding of complexity theories in social science arena. Given the increasing interest of complexity theories in social science research, agent-based model provides not only an important methodological approach, but also a tool for the development of theories of socially complex systems.

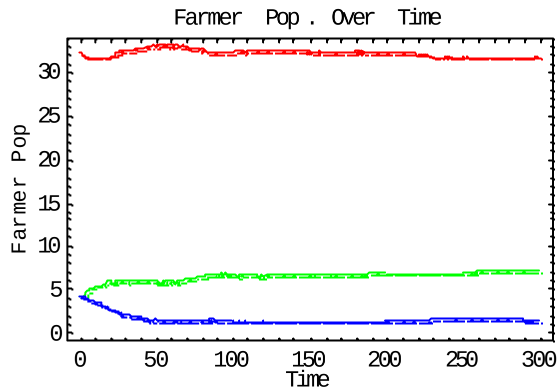
Appendix 1: Simulated Market Environment (An Agricultural Supply Chain)

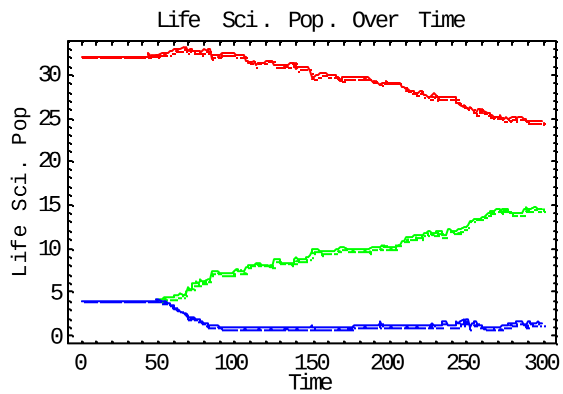
Information Structure of Product-Markets



Appendix 2: Monte-Carlo Simulation run for 300 period over 35 independent runs with VC1 premiums at 0.25 (Farmer) and 0.15 (Life Science) and VC2 premiums with 0.1 (Farmer) and 0.1 (Life Science)







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