RURAL ECONOMY

A Coevolutionary Approach to Understanding the Paradox of Social Pressures versus Economic Efficiency Across the World's Food Chains

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Staff Paper 02-04

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In recent years considerable social pressure has been brought to bear on commodity food chains throughout the world. Events such as the introduction of bioengineered crops, the discovery of BSE in beef and instances of food contamination directly leading to human illness have focused attention on the food supply chain. Traditionally the operations of commodity-based food chains attracted relatively little attention from anyone not directly involved in agriculture and food systems. And, even within those logistical and marketing systems, their low margins and scale efficiencies tended to inhibit innovation.

Now, however, the tension between social pressures and food chain economic efficiency has become an issue of concern. On the one hand, loud voices "demand" rapid and dramatic change to the commodity-based system to provide each consumer with any physical and information attribute that might be of interest. Conversely sector decision makers know that consumers, voting with their pocketbooks, will discipline those food chains that venture too far in adding costs to final products.

This setting extends beyond, however, the normal marketing question of whether sufficient numbers of consumers will buy a new product and at a sufficiently high price to attain profitability. In food chains today, decision makers are besieged with messages that are contradictory and paradoxical. For example, at the same time that there is a potential threat that US commodity exports are being restrained because of international resistance to bioengineered crops, US soybean and cotton exports (both primarily produced from bioengineered seeds) are at record levels (Abbott, 2001).

Because every supply chain is a collection of economic transactions, it is natural to expect economic analysis to be able to provide insights as to the future directions of the food system. Stated very simply, one would expect that, if consumers are willing to pay for additional product attributes (both physical and informational), agricultural and food systems would respond to provide those attributes. However, it is always difficult to estimate what consumers will actually pay for attributes they are not now receiving. And specific consumer segments, potentially delineated by income, geography, demographics or several other criteria, may have markedly different preferences for these attributes. Food chains, themselves, are systems and change often requires substantial initial investment, which can forestall innovation even if in the long run such change would be economic. Further, if the presence or absence of a certain attribute is imposed by government regulation, the competitive dynamics of change can be significantly different than would be the case if such regulations didn't exist.

Despite these complexities, private and public sector decision makers with interest in food supply chains have to make decisions today whose outcomes will be significantly affected by the future resolution of these paradoxes. The purpose of this paper is to describe an innovative conceptual approach and to present a specific analytical framework that can be employed to enhance our understanding of the" paradoxical" forces pressing for change and the likely future directions of change.

These paradoxical forces underscore a conceptual dilemma confronted by organizational theorists. Changes in markets such as those dictated by the increasingly discriminating food consumer are considered as an exogenous market force that drives the dictates of food market activities. This exogenous influence places primary emphasis on the "deterministic" forces of the market dictating future market changes (Astley and Van De Ven, 1983). Conversely, "voluntaristic" viewpoints (Astely and Van de Ven, 1983) contend that purposeful behavior of food sector participants can alter the demands of food consumers. Such diametrical positions reflect the polar arguments of market pulling and technology pushing forces that confront food market systems today. In contrast, the analysis framework advanced here employs a coevolutionary perspective (Baum and Singh, 1994; Lewin and Volberda, 1999) to explain the organizational-environmental interrelations confronting food supply chains. These coevolutionary processes exploit complex and dynamic relationships spanning different levels of aggregation (Baum and Singh, 1994).

To make this coevolutionary perspective operational, the paper's conceptual approach draws from complexity theory (Jantsch, 1980; McKelvey, 1999), Austrian economics (Hayek, 1967; Kirzner, 1979) and social networking (Granovetter, 1973) to better understand the effect of paradoxical forces through complex coevolutionary processes. This coevolutionary approach incorporates both perspectives, environmental determinism and the voluntaristic pursuits of managerial choice, as reciprocally interdependent where each shapes the impact of the other. This approach not only improves our understanding of the complexity of paradoxical influences that impact food market systems but also presents an alternative viewpoint of organizational-environmental relations. In addition, this framework provides analytical advances in its use novel use of agent-based modeling (Lane, 1993) in a specific agricultural supply chain context.

The remainder of the paper is comprised of the following sections. First, the underpinnings of the suggested approach, and its links to complexity theory, Austrian economics, and social networking, will be detailed. Such an approach provides the conceptual basis to understanding coevolutionary processes. Then, the approach will be defined within the context of a specific modeling framework and application to a food market chain. Finally, implications for application will be presented.

Conceptual Approach

In reality (and for purposes of this paper), food supply chains exist as complex systems (Ng, 2001). Organizations of varying size and scope are interlinked within these chains. For example a multinational chemical company's product may be sold to thousands of farmers through a cooperative owned by part but not by all of those farmer customers. Farm output typically is aggregated from those farms and then processed into food products for consumers. Again often firms of varying organizational form, size, and scope perform the processing, distribution and retail functions. Governmental and other non-profit organizations also affect the effectiveness of food chain operations and can be impediments and/or catalysts for change. Their influence is often included within the context of the business and general environment surrounding the food chain. Although one food chain is comprised of numerous linkages, the global food sector is the amalgamation of all such chains that differ geographically and culturally. Both individual food chains and the totality of the global food sector co-exist as inter-related complex systems.

An Overview of Complexity Science

Although originating in the biological and physical sciences, complexity theory has started to receive interest from economists, organization and management theorists (Lewin, 1999). A distinctive feature of complexity science is its attention to the joint roles of micro and macro influence in shaping the trajectory of a system's evolution, what Prigonine and Stengers (1984) refer to as "contemporary determinism".

From a complexity science perspective, coevolution is a result of the decentralized properties of a complex system (Kauffman, 1993). A complex system consists of micro entities (i.e. people, ants, molecules etc.) with "stochastic and idiosyncratic" behaviors whose collective interactions yield non-linear feedback behaviors (McKelvey, 1999). The decentralized orientation of complex systems allows for the depiction of evolving, multi and bi-directional causal relations among the micro entities comprising such a system (Baum and Singh, 1994; McKelvey, 1999). Within a network setting, these complex interactions coevolve as the behavior of any one micro entity inter-relates with the behaviors of others (Kauffman, 1993).

Nested Coevolution: Local And Macro Levels of Organization

Based on these properties of a complex system, the coevolution of organization-environmental relations is driven by a "nested" hierarchal process (Baum and Singh, 1994). Nested hierarchies consists of part and whole relationships where "wholes are composed of parts at lower levels of organization, and are themselves parts of more extensive wholes" (Baum and Singh, 8, 1994) such that reciprocal interactions occur at not only within different levels of aggregation, but also between such levels. For example, some individual farmers perceive that there are gains to be had from producing crops organically or without the use of bioengineered seeds because some consumers have expressed a desire for such products. In many instances, connecting the consumers to those sources of farm output requires the collaboration and involvement of collection, processing and distribution entities. Such collaborations consist of complex social and economic relations that extend beyond farm production sectors to include other food chain participants and, thus, each individual contributes or is 'part' of the greater functioning and behavior of the 'whole' food chain system.

Drawing from the decentralized property of complex systems, lower levels of organization consist of "local" coevolutionary processes. "Local" coevolution involves a reciprocal interaction between the behavior of the individual micro entity and its environment consisting of interactions and behaviors of other micro entities in its "local" vicinity (Kauffman, 1993). Through interactive influences, changes brought upon by the behavior of a micro entity influence the “local” environment and in turn changes in this environment affect the behavior of the micro entity. As a decentralized system is comprised of many such interacting entities, this local coevolution occurs in "parallel" for every individual in a complex system. As a result, "local coevolutionary" processes in one region of a complex system impact "local coevolutionary" processes in other regions (Kauffman, 1993). Kauffman (1993) describes these local interactive behaviors as a "patching" process.

The collective behaviors of these “local” coevolutionary processes comprise the “macro” environment in which this macro environment exhibits a distinct behavior separate from local processes. This imparts a nested coevolutionary logic. That is, the composite behavior of all such local coevolutionary processes is “nested” within a higher level of macro organization to which such macro behavior is more than the sum of behaviors among local coevolutionary processes. This reflects a non-linear property of complex systems where complex behaviors such as bifurcations, edge of chaos and chaotic macro expressions can occur (Kauffman, 1993).

Nested Coevolution: Non-Linear Behavior Of Positive And Negative Feedback

This nested coevolution consists of two dominant forms of non-linear interactions termed positive and negative feedback. Positive feedback self-amplifies the stochastic behavior of micro entities in causing “chaos” and the resulting destabilization of the macro behavior of a complex system (Jantsch, 1980). This is also termed a “bifurcation” event where opportunities for the reconfiguration of the internal system of relationships cause a symmetry breaking process to occur (Prigonine and Stengers, 1984).

The significance of positive feedback in motivating the onset of “bifurcation” is that “individuals matter” in causing potentially a dramatic alteration to the internal arrangements of a complex system (Jantsch, 1980). Stated differently, an individual’s voluntaristic pursuits can cause widespread macro bifurcated change in food market systems. This is because positive feedback self-amplifies the stochastic behaviors of micro entities to cause the bifurcation of not only local coevolutionary processes but, through positive feedback interactions to other local coevolutionary processes, can cause a macro or system wide bifurcation. This yields the deconstruction or radical transition in macro behaviors. Such an argument is consistent with Kauffman's (1993) depiction of "edge of chaos" behaviors.

One example of positive feedback and its related consequence of bifurcation is the use of information technology in the meat industry. Because of consumer concerns regarding food safety and other social factors, some meat processors are investing in information technology, which will allow for precise traceability between their output as specific cuts and meat products and the source of individual animals they purchased as input. If profits accrue from this innovation, the innovating firm will attempt to expand these capabilities. Further, learning curve effects from use of these innovative resources should allow for operating costs to be reduced. These forces act as positive feedback, not just to the innovative firm, but also to competing meat processors in the market. That is, the subsequent adoption of this innovation can yield self-reinforcing influences which in the extreme could result in the bifurcation of food chain markets.

However, in mitigating the onset of "bifurcated" behaviors, negative feedback interactions exhibit a "macro deterministic" influence on local coevolutionary processes (Jantsch, 1980; Kauffman, 1993). A system's negative feedback consists of a dampening or equilibrating influence such that an initiated change caused by the stochastic behaviour of an individual is restored to the system's long-term equilibrium state (Jantsch, 1980). The system's negative feedback behaviour, therefore, is responsible for maintaining a stable and predictable equilibrium (Jantsch, 1980). In the example of innovation to allow for traceability of meat cuts, the innovating firm may expect to receive premiums for its products with these information attributes. However, the response of competitors (lowering prices and/or making their products more desirable through other means) could restrict the profits accruing from the innovation. These negative feedback effects act to lessen the likelihood that the innovation will be successful and, in so doing, maintain the preceding equilibrium and mitigate potentially bifurcating behaviours.

Although this negative feedback operates as a macro deterministic influence, such feedback originates from "self-organizing" processes found in local coevolution. Specifically, in a complex system, local coevolutionary processes can give rise to the expression of "self-organizing behaviors"

(Kauffman, 1993; McKelvey, 1999). In the absence of external intervention, “self-organization” refers to the internal experimentation of micro entities that yields the emergence of ordering structures (Kauffman, 1993). A prerequisite for self organized behaviours is the existence of sufficient internal diversity or “stochastic idiosyncrasy” (McKelvey, 1999) to allow for ordering structures and behaviours to emerge (Kauffman, 1993). Hence, so long as local processes consist of stochastic behaving agents, negative feedback influences can arise from the self-organizing behaviours found in such local processes. This negative feedback in turn acts as a macro deterministic force that exerts a dampening effect on those local coevolutionary processes that exhibit positive feedback.

Consequently, through both positive and negative feedback interactions, the interplay of local and macro coevolutionary forces jointly shapes complex system behaviour. This interplay of non-linear behaviours drives the nested coevolution of organizational-environmental relations. However, since complexity and coevolutionary theories originate from physical and natural sciences, a “socialized” conception of this nested coevolutionary is developed from an Austrian economic perspective.

Alert and Subjective Entrepreneurship

Decentralized market processes are central to Austrian economics (Hayek, 1967). Therefore elements from Austrian economics are well suited to conceptualizing the decentralized orientation of the nested coevolutionary process of food supply chains. In particular, decentralized market processes arise from the subjective and alert tenets of Austrian economics (Ng, 2001). Subjectivism is based on the insight that every entrepreneur is purposeful in choosing plans based on their subjective perceptions, beliefs, wants, and knowledge. Subjectivism is also the basis for an entrepreneur’s “alertness” to grasp for undiscovered opportunities in the market environment (Kirzner, 1979). For example, providing wheat that is more consistent in its quality attributes can cut costs in the baking process and provides the potential for additional value for suppliers to baking companies. Further, the existing low commodity prices encourage farmers and their representatives to search for options to create new sources of value. Hence, alertness can viewed as the discovery of “value added” possibilities in food chain systems.

However, more formally, alertness is defined as an entrepreneur's intentionality to seek opportunities in an environment by recombining the diverse knowledge contained in plan choices of other subjective and alert entrepreneurs. Because above normal returns (entrepreneurial profits) arise from asymmetric knowledge (Kirzner, 1979), alertness is the discovery of profit opportunities from recombining subjective knowledge experiences in a decentralized and "fragmented knowledge" market environment (Kirzner, 1979). Alertness can involve the seeking of opportunities from plan imitation, "revising" the failed plans of others (Kirzner, 1979), and Schumpeterian innovations.

Local Social Coevolution: Entrepreneurship and Social Networks

Based on subjective and alert entrepreneurship, "local" coevolutionary interactions of a social dimension consist of reciprocal "social" interactions where an entrepreneur's knowledge and behavior shapes and is shaped by the social knowledge or "social rules"(Hayek, 1967) of its local environment. With alert and subjective entrepreneurs, "local" interactions consist of the recombination and diffusion of the diverse knowledge or plan experiences in the entrepreneur's social network. These social interactions are confined to interactions among the members of an entrepreneur's social network. This is because subjectivism imparts "bounded rational behaviors" and, thus, social interactions are confined to local processes. As a result, this imparts the "local" dimension of coevolution.

Historically the connotation of local in agricultural and food systems implied relatively limited geographic areas. The advent and adoption of information technologies, especially e-mail and the World Wide Web allows, even geographically remote, farmers and food sector decision makers access to a wider range of information sources. Coupled with globalization, these technologies are changing the geographic dimensions of local networks (Sonka, et.al., 1999). However, even when augmented with technology, the "locality" of social interactions is nevertheless constrained by the cognitive limits imposed by subjectivism.

Diffusion and recombination of knowledge in the local environment result in the emergence of "social rules". Through a process of dynamic competition (Hayek, 1978), each alert entrepreneur tries to discover better or cheaper ways of doings things by either drawing on their subjective knowledge experiences or by recombining the knowledge (i.e. plan choices) of others in the network so as to create an improved plan (Ng, 2001). Some plans will succeed, while others will fail. Those plans that fail constitute "social rules" reflecting the collective knowledge experiences of past failed plans (Hayek, 1967). However, for plans that succeed, social rules also reflect successful or “legitimate” (Scott, 1995) knowledge / plan experiences.

The social rules of the local environment in turn build upon the individual entrepreneur’s existing knowledge allowing potentially more profitable plans to be formulated. However, the entrepreneur’s enacted plans in turn shape the development of social rules within the social network (Ng, 2001). As new plans are formed, failures and successes can arise and social rules become further shaped by the evolving knowledge experiences of alert entrepreneurship (Ng, 2001). As a result, an individual entrepreneur contributes to shaping the development of social rules, but is also shaped by the guidance influence of social rules in the social network. The result is a reciprocal "local" coevolution of individual knowledge and social rules.

Food industry practices or conventions employed in food markets are examples of social rules. As a response to low commodities prices and signals that consumers desire information as to how their food was produced as well as high quality food, a large number of efforts have been initiated to certify or provide quality assurance regarding the practices (i.e. formation of new social rules from alertness) used to produce agricultural output. Not all of these competing systems are likely to be successful as social rules in the long run, although it seems likely that some will.

Social Interactions: Social Networks and Non-Linear Behavior

Because this “localized” coevolutionary process is dependent upon social interactions, the entrepreneur's choice of social network relations of “weak information ties” and “strong information ties”(Granovetter, 1973) generate, respectively, positive and negative feedback behaviors (Ng, 2001). These information ties serve to capture the non-linear reciprocal relations found between local and macro coevolutionary processes.

Positive feedback of innovative behaviors. Positive feedback is characterized by those social interactions involving the exchange of knowledge among innovating entrepreneurs who form weak information ties (Ng, 2001). According to social network literature, “weak information ties” arise from information ties to dissimilar agents (Granovetter, 1973). Information transmission through weak information ties is, therefore, largely of novel content from the perspective of the individual entrepreneur.

Weak information ties can fuel Schumpeterian innovation in the local network, if such ties result in *novel* recombination of resources (Ng, 2001). The access to diverse sets of knowledge / plan choices provides for experimentation and, thus, innovation (Ng, 2001). As successful plan choices stimulate innovative rents, other “alert” entrepreneurs will strive to form weak information ties to the innovating entrepreneurs. A self-amplifying process of successive recombinations of plan choices leads to increasingly innovative plans. Therefore through this positive feedback process, an innovative entrepreneur who forms weak information ties can cause the bifurcation of the existing social rules and plan choices within the social network/local environment (Ng, 2001).

Building upon this argument, local interactions from the formation of weak information ties can result in the bifurcation of not only one local social network, but also to the bifurcation of other networks and then to overall macro bifurcation. The extent of such bifurcations is dependent on the extent of iterative interactions used to generate such self-amplifying influence (Kauffman, 1993). Therefore, the number of members in social networks with weak information ties to the bifurcating network affects the rate and extent of positive feedback behavior. In today’s food system, some players in the food sector are likely to have much more extensive weak information ties than are others. For example, a multinational food processor with operations in the United States and in Europe is being forced to deal with two very different social agendas that affect the sourcing of their inputs. In the short run, operating efficiency is likely to be slightly reduced; however, in the long run the exposure to markets with these very different social rules may provide valuable information for innovation. A competing food processor, which operates in only the United States or in Europe, may find that the short run efficiency gains come at a severe long run cost if the multinational can leverage the knowledge creation across both geographies.

Negative feedback interactions. Unlike positive feedback, negative feedback is manifested by social interactions involving the dissemination of social rules among those entrepreneurs who form strong information ties (Ng, 2001). Strong information ties breed conformity and social consensus through the shared understanding of social rules (Ng, 2001). Consistent with social institutional and organizational ecology literature (Scott, 1995), these social rules reflect the pressures of the social environment on entrepreneurs to conform to institutionalized norms of practice. Entrepreneurs have incentives to form strong information ties, because the access to social rules assists in the formulation of correct plans and reduces the uncertainty associated with trying new plans (Ng, 2001; Scott, 1995).

The transmission of social rules through strong information ties has a negative feedback or dampening effect that counters the bifurcating influences introduced by "innovative plans". The recombination of similar plan experiences through strong information ties contributes to the diffusion of social rules to which plans converge towards increasingly homogeneous plan choices (Ng, 2001). Since bifurcating behaviors rest upon the iterative recombination of *diverse* elements, this increasing homogeneity of plan choices circumvents those innovative experimentations necessary for positive feedback to occur (Ng, 2001).

However, unlike social institutional and organizational ecology theories that presuppose the existence of social rules imposed from the macro social environment, these social rules originate from the self-organizing process of local coevolution (Ng, 2001). The reciprocal "local" coevolution of individual knowledge and social rules generates the internal experimentation necessary for the expression of self-organization. According to Hayek (1967), the self-organization of markets occurs from the entrepreneurs' trial and error efforts to form successful plans. In particular, these efforts are jointly determined by an entrepreneur's alertness and those social rules imparted by the experimentation efforts of other alert entrepreneurs in the social network. As a result, the social rules found in one's network inform alert entrepreneurial choice and in turn such choice informs the social rules to others. This reciprocal interaction results in the self-organization of local social networks (Ng, 2001). As successful plans are revealed, entrepreneurs have incentive to form strong information ties so as imitate the successful plan formulations (Ng, 2001). The formation of these strong information ties diffuses the social rules of successful plans throughout the social network. A self-organizing process results as the plan diffusion creates negative feedback tendencies for plan imitation / conformance (Ng, 2001).

The macro environment is comprised of the collective behaviour of such local coevolutionary processes. Social rules arising from the self-organization processes of each social network, thereby, constitute the collective social rules of this macro environment. Hence, through the self-organization of local coevolutionary processes, the emergence of local social rules gives rise to the endogenous formation of the macro environment's social rules. The social rules of the macro environment in turn constitute a macro deterministic influence that dampens local coevolutionary processes in social networks that exhibit positive feedback.

Nested Coevolution: Macro Coevolution of Knowledge and Social Relations

Driven by the self-organization of local coevolutionary processes, the macro environment is subjected to another form (i.e. more hierarchical form) of coevolution where the collective social network relations of strong and weak information ties (i.e. found in all local coevolutionary processes) coevolve with the collective knowledge of society. In particular, because the "local" coevolutionary processes contribute to the reciprocal interaction of individual knowledge with the social rules of the local environment, these local reciprocal interactions result in an evolving pattern of social network relations consisting of changes in strong and weak information ties (Ng, 2001). Through such changes in network relations the ordering influences of negative feedback and the chaotic/bifurcating forces of positive feedback contend with each other to mitigate and accelerate, respectively, forces for change. The collective behavior of all such non-linear processes affects the macro coevolution of the system.

Specifically, through positive feedback influences, local coevolutionary processes shape macro knowledge and social network relations and, through negative feedback, the macro environment shapes the underlying local coevolutionary process. Through the myriad of these non-linear influences that comprise the macro environment, the nested coevolutionary behavior of a complex system can endogenously create conditions for its own deconstruction. As "local" social rules become increasingly disseminated, the revealing of successful plans through the guidance role of social rules diminishes competitive advantages that stems from asymmetric knowledge (Ng, 2001). In these increasingly competitive conditions, entrepreneurs will no longer rely on the guidance influences of social rules, but rather experiment to discover innovative plans (Ng, 2001). Entrepreneurial innovative plans become the catalyst for a system wide bifurcated change, reflective of Schumpeter's "creative destruction" (Ng, 2001).

Modeling Framework

Unlike econometric methods that depend upon a logic of uni-directional causality, a coevolutionary approach requires methods that encompass multi and bi-directional causal relations that extend to many hierarchical levels of organization. Agent-based modeling (Lane, 1993) offers one such method (Kauffman, 1993). Agent-based modeling relies upon the construction of computer simulations comprised of interacting heterogeneous and rule-based agents operating in artificial worlds (Lane, 1993). The goal of agent-based simulation is to develop insight on non-linear processes exhibited by complex systems (Lane, 1993). It has been used to examine bifurcated, chaos, edge of chaos and self-organizing behaviors (Ng, 2001) to which such understanding can provide particularly useful insight on the complex processes found in food chain systems. These outcomes can reveal behavior not expressible by mathematical models, which often yield intractable analytic solutions when complex non-linear dynamics are included (Axtell, 2000). Consequently, agent-based method has considerable potential for investigating those paradoxical influences that impact the behavior of food supply chains within a nested coevolutionary framework.

An Example Environment

Although the modeling framework that will be presented is general in nature, its presentation forwards an analytical representation of a nested coevolutionary approach. Such an application has not been done to date. To provide a context for its use to address food chain evolution, a brief description of an example application will be provided. A complete description of this example can be found in Ng (2001). In this example setting, the subjective and alert entrepreneurs are populated in a supply / value chain market structure. A supply chain market structure was utilized because it incorporates the complex interactions typical of food supply chains (Ng, 2001).

Applied to the context of an agricultural-food market system, this supply / value chain consists of an exogenous end-user market sequentially connected to three supply stages –the food processor, farmer and life science stages. Each supply stage contains alternative product-markets. For grains and oilseeds in today's environment, the co-existence and competition between the traditional commodity, identity preserved, and vertical integration through financial ownership product-markets is of particular interest. In the commodity product-markets, market prices coordinate or link the adjacent stages of the supply chain. Contractual arrangements (often tied to commodity market prices) are used to coordinate identity preserved product-markets. In a vertically integrated product-market, however, production costs and administrative controls might be the primary coordination devices. Again the modeling framework will be described in general terms and the preceding examples are offered only to illustrate potential application.

Heterogeneous and Adaptive Agents: Subjective and Alert Entrepreneurs

In simulating this nested coevolutionary process, the subjective and alert entrepreneur is used to operationalize the heterogeneous and rule-based behavior of agents. The agent behavior is modeled through two interrelated choices: behavioral rules and interaction rules (BRIR) and product-market choices. BRIR are heuristics that reflect the selection of resource/input combinations from the social interactions an entrepreneur conducts with its social network/local environment. These resource / input combinations determine the entrepreneur's plan to produce a product in a given product-market. These BRIR choices yield "local" coevolutionary process because they involve the recombination of knowledge experiences (i.e. plan choices) from the dynamic social interactions an entrepreneur conducts with its local environment (i.e. evolving social. network). These social interactions transmit failed and successful plan choices (i.e. social rules) within an entrepreneur's social network. As a result, an entrepreneur's BRIR choice is central to the local coevolutionary process.

Because there are distinct resource/input combinations and thus plans that are more profitable for some product-markets than others, the "optimal" choice of BRIR influences an entrepreneur's product-market choice. An entrepreneur must choose to compete in a specific product-market. In the previously described example, the entrepreneur must choose either the commodity, identity preserved or vertically integrated product-market. Based on these different product-markets, social interactions between similar and dissimilar product-markets constitute strong and weak information ties, respectively. Therefore, local coevolutionary processes can consist of the reciprocal interaction with in and between each product-market while the collective behavior of entrepreneurs in all product-markets constitutes the macro coevolutionary behavior of the market system.

BRIR Choice

The set of BRIR available to the entrepreneur is summarized in Table 1. There the alternative choices for an alert and subjective entrepreneurial behavior are defined as rule following (2 alternatives) and / or rule generating (3 alternatives) behaviors.

Table 1: 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. Generates Negative feedback (order) behavior.
2) Copy and revise upon the most profitable entrepreneur 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. Generates Negative feedback (order) behavior.
Rule-generating: Behavioral Rules	**Corresponding: Interaction Rules**
3) Adopt one innovative input 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. Generates positive feedback behavior.
4) Choose the first innovative input that one has not used before.	No social interactions. Generates positive feedback behavior.
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 lead to the formation of weak information ties. Generates positive feedback behavior.

Alert and Subjective Entrepreneurship: Trade Off Function and Constraints

An entrepreneur’s subjective perception of market opportunities is captured by a trade off function (equation 1 and its associated constraints, 1a-e), which determines the entrepreneur’s “optimal” choice of BRIR. For a given optimal product-market choice, $I^{*}_{s,k,t}$, this trade off function (Eq. 1) is indexed by the k^{th} entrepreneur residing in a sub-sector of an industry defined by a supply stage, *s*, (i.e. upstream/downstream stage) at time t.

Equation (1)

$$Trade\,Off_{s,k,t}\left(BRIR^{*}_{s,k,t} \mid I^{*}_{s,k,t}\right) = \underset{BRIR}{Max}\left\{\begin{array}{l}\left[P_{s,k,t}(\overline{\eta_{s,k,t}} \mid I^{*}_{s,k,t})\, F^{Subj}_{s,k,t}(PL^{*}_{s,k,t}(X_{s,k,t}(BRIR_{s,k,t}) \mid A^{Subj}_{s,k,x,t}, I^{*}_{s,k,t}))\right] \\ -\left[\sum_{x=1}^{8} R_{s,k,x,t}\,(\overline{\eta}_{s,k,t} \mid I^{*}_{s,k,t})\left[\begin{array}{l} X_{s,k,t}(BRIR_{s,k,t}) \\ -X_{s,k,t-1}(BRIR_{s,k,t})\end{array}\right]\right] \\ +\Pi^{PL}_{s,k,-t}(PL^{PL}_{s,k,-t} \mid I^{*}_{s,k,-t})) - Asp_{s,k,-t}(I^{*}_{s,k,-t})\end{array}\right\} \quad \forall s,k,t$$

s.t.

$$(1a) \quad A^{Subj}_{s,k,x,t}(I^{*}_{s,k,t}) = \left[1 + Uniform_{s,k,t}[\overline{\mu_A}, \overline{\sigma_A}]\right]\overline{A_{s,i,x,t}} \qquad \forall s,k,x,t$$

$$(1b) \quad F^{Subj}_{s,k,t}(BRIR_{s,k,t}) = \sum_{x=1}^{8} A^{Subj}_{s,k,x,t}(I^{*}_{s,k,t}) \cdot X_{s,k,t}^{\overline{\alpha_{s,k,t}}}(BRIR_{s,k,t}) \quad \forall s,k,x,t$$

$$(1c) \quad X_{s,k,t=0} = Uniform_{s,k,t}[\overline{\mu_x}, \overline{\sigma_x}] \qquad \forall s,k,x,t$$

$$(1d) \quad \Pi^{PL}_{s,k,-t}(PL^{PL}_{s,k,-t} \mid I^{*}_{s,k,-t}) = \frac{\sum_{t=1}^{T-1}\Pi_{s,k,t}((PL^{PL}_{s,k,t} \mid I^{*}_{s,k,t}))}{\sum_{t=1}^{T-1} No.\,PL_{s,k,t}(I^{*}_{s,k,t})} \bullet \frac{\sum_{t=1}^{T-1} No.\,PL^{PL}_{s,k,t}(I^{*}_{s,k,t})}{\sum_{t=1}^{T-1}\sum_{PL=1}^{256} No.\,PL^{PL}_{s,k,t}(I^{*}_{s,k,t})} \;\forall s,k,-t$$

$$(1e) \quad Asp_{s,k,-t}(I^{*}_{s,k,-t}) = \frac{\sum_{t=1}^{T-1}\sum_{PL=1}^{256}\Pi_{s,k,t}(PL^{PL}_{s,k,t} \mid I^{*}_{s,k,t})}{\sum_{t=1}^{T-1}\sum_{PL=1}^{256} No.\,PL^{PL}_{s,k,t}(I^{*}_{s,k,t})} \qquad \forall s,k,-t$$

Subjective and alert entrepreneurship involves the choice of BRIR so as to maximize the trade off function subject to a series of behavioral constraints. The problem confronting the entrepreneur can be viewed as a variant of an evolving Stackelberg game of imperfect knowledge with n persons that exhibit non-linear behaviors. In describing the entrepreneur's behavior, the entrepreneur's subjectivity is depicted in term of their perception of the marginal productivity of the resource/input combinations (Eq. 1a), $A^{Subj}_{s,k,x,t}(I^{*}_{s,k,t})$. This subjectivity can be substituted into a Cobb-Douglas production function (Eq. 1b), $F^{Subj}_{s,k,t}(BRIR_{s,k,t})$, that is separable into unique resource / input combinations, $X_{s,k,t}$. In addition, each entrepreneur has an initial resource / input allocation (Eq. 1c) depicting an initial heterogeneity of plan choices, $PL_{s,k,t}(X_{s,k,t}(BRIR_{s,k,t}) \mid I^{*}_{s,k,t})$. Social rules as production experience are defined in terms of the average past profits, $\Pi^{PL}_{s,k,-t}(PL^{PL}_{s,k,-t} \mid I^{*}_{s,k,-t})$, earned by an entrepreneur for a given plan choice, PL, (Eq. 1d). The addition of equation 1d to the tradeoff function allows entrepreneurs to learn from experience. Plans that have earned poor profits will reduce the tradeoff value and, thus, the BRIR associated with such plans will be avoided. This depiction captures the social rules of local coevolutionary processes (Ng, 2001). In addition, because an entrepreneur's social network evolves with changes in knowledge, the diversity of social interactions with other entrepreneurs enables each entrepreneur to capture the macro social rules of the environment (i.e. knowledge of other social networks).

Lastly, entrepreneurial "aspirations" (Eq. 1e), $Asp_{s,k,-t}(I^*_{s,k,-t})$, stimulates entrepreneurial alertness to enact an "optimal" BRIR choice. An entrepreneur's aspiration is defined in terms of the average product-market profits for all plan choices conducted over T-1 periods of entrepreneurial experience. With an entrepreneur's aspiration as an additional argument to the entrepreneur's trade off function (Eq. 1), those BRIR yielding plans that confer "perceived" profits in excess of aspiration levels (i.e. average product-market profits) will generate higher trade off values. Therefore, there is a greater propensity to identify and pursue such BRIR choices. In addition, this aspiration is also used as a behavioral condition (condition 1) where the "optimal" BRIR is chosen only when the previous periods entrepreneurial profits, $\Pi_{s,k,t}(PL^{PL}_{s,k,t} \mid I^*_{s,k,t})$, fall below an entrepreneur's aspirations. Therefore, entrepreneurs with higher aspirations (higher subjective expectations of profits for a given product-market) will have a greater tendency to seek out "optimal" BRIR choices.

$$\textit{Condition}\ 1$$
$$\Pi_{s,k,t}(PL^{PL}_{s,k,t} \mid I^*_{s,k,t}) < Asp_{s,k,-t}(I^*_{s,k,-t}) \qquad \forall s,k,t\ .$$

Product-Market Choice

An entrepreneur's product-market choice, $I^*_{s,k,t+1}$, takes into account the optimal BRIR choice, $BRIR^*_{s,k,t}$, in deciding to enter a product-market. As shown in equation 2, this product-market decision is conducted by taking the sum of the maximum of the first term that measures the proportion of the cumulative entrepreneurial profits earned in each product-market and the second term that measures the proportion of the product-market specific resource / input combination, $\hat{X}_{s,k,x,t}(BRIR^*_{s,k,t} \mid I^*_{s,k,t})$, currently used by the optimal BRIR choice. This second term is used to capture those resource / inputs unique to an entrepreneur's product-market choice.

$$(2) \quad I^{*}_{s,k,t+1} = \underset{I_{s,k,t}}{Max}\left[\frac{\sum_{t=1}^{T-1}\sum_{PL=1}^{256}\Pi_{s,k,t}\,(PL^{PL}_{s,k,t} \mid I^{I}_{s,k,t})}{\sum_{I}^{3}\sum_{t=1}^{T-1}\sum_{PL=1}^{256}\Pi_{s,k,t}\,(PL^{PL}_{s,k,t} \mid I^{I}_{s,k,t})} + \frac{\hat{X}_{s,k,x,t}\,(BRIR^{*}_{s,k,t} \mid I^{*}_{s,k,t})}{\sum_{\hat{X}}\hat{X}_{s,k,x,t}\,(BRIR^{*}_{s,k,t} \mid I^{*}_{s,k,t})}\right] \quad \forall s,k,t$$

$$(2a) \quad I_{s,k,t=0} = Uniform_{s,k,t}[\overline{\mu_I}, \overline{\sigma_I}] \qquad \forall s,k,t$$

An entrepreneur's choice of product-market is, therefore, based on both past product-market experience as well as the current resource / input combination of the optimal BRIR. The entrepreneur chooses the product-market that maximizes these arguments. This optimal product-market choice is also subject to an initial product-market constraint (Eq. 2a) where each entrepreneur initially has a unique perception of the relative attractiveness of the different product-markets.

Implications for Application

The analytical model presented above is based upon a novel approach to understanding organizational-environmental relations: a nested micro-macro system of individual entrepreneurial choices that simultaneously drive and respond to market evolution. The application of this model to a food supply chain context highlights the paradoxical forces that characterize complex food marketing systems. The proposed analytical model offers an alternative to conventional welfare economic assessments. It not only incorporates complex systems behavior but more importantly, it rests on a different conceptual basis where food sector participants influence welfare outcomes explicitly through their investment choices and interactions with other agents that are horizontally and vertically tied to them. That is, aggregate industry and supply chain behavior arises from the choices of alert and subjective entrepreneurs in an explicit manner – one doesn't have to resort to "representative" homogeneous agents or to tenuous aggregation rules.

With specific modifications to the general analytical framework above, other behaviors of the self-organized supply chain can be examined: the consequences of investment choices in R&D, of entry into new product markets, and of building networks among alliance partners. Decision choices in complex systems such as food supply chains can often yield unexpected outcomes because of interconnectedness and nonlinearities. In the extreme, such decisions can result in bifurcating behaviors. The ability to better anticipate unintended consequences has significant value for food policy makers and sector participants, accounting for complex coevolutionary processes not traditionally incorporated in deterministic, simulation techniques. Complexity science, when applied to natural systems, has shown that highly structured, rigid systems can cause unfathomably chaotic change when a bifurcation event occurs. With a highly regulated or highly interconnected social system, such as a food product supply chain, one can expect chaotic outcomes from big events such as a major food safety failure (BSE?) or the entry of a new competitor (Wal-Mart in Europe?). One can also expect that a thousand small changes within the normal bounds of regulatory control will lead to a greater-than-the-sum-of-parts outcome. For example, how many small outbreaks of *E. coli* and S*almonella*, coupled with "normal" merger activity in food processing, would be sufficient to erode the American consumers' confidence in the food supply?

Another application concerns the management of knowledge networks through strong and weak information ties. This type of social capital in food supply chain networks can be a source of competitive advantage, just as physical and human capital assets are the acknowledged bases for scale economies and for exploiting experience curves. From a managerial perspective, simulation of alternative chain-level strategies could enhance understanding of the dynamics of knowledge sharing and knowledge protection (isolation from competing chains). In addition, attention to the knowledge creation and diffusion processes in the new knowledge economy can be of increasing pertinence to agricultural policy makers for devising intellectual property right schemes that maximize food chain welfare. That is to say, welfare assessment of alternative intellectual property rights regimes (i.e. breadth and time duration) can be better examined through explicit analysis of coevolutionary system behavior than through static analyses.

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