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Market-level effects of firm-level adaptation and intermediation in networked markets of fresh foods: A case study in Colombia

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ABSTRACT

This paper presents a multi-agent simulation that studies market competition in a multi-stage negotiation with both direct sales and intermediation, in the presence of cost heterogeneity at the agent (i.e., producer) level. Producers sell their products according to an adaptive reinforcement strategy. Product is sold to clients (small shops and consumers) according to two types of marketplaces, which are characterized by whether they obtain the product from intermediaries or directly from producers. The model is applied to the case of a networked market of potato (*Solanum tuberosum*) producers in Bogotá, Colombia, and calibrated to real data. The results reveal that, contingent upon the number of producers, number of intermediaries, unit transportation cost and producers' culture, intermediation might lead to greater traded quantities than sales through farmers' (local) markets. Also, we found that increasing the intensity of competition among intermediaries is at odds with the increase of producers' long run profit. Thus, we conclude that intermediation still plays an important role to maintain the supply ecosystem, especially when transportation costs are important in a network of isolated and fragmented network of producers.

1. Introduction

In recent years, worldwide interest in food security has grown given its importance for the urban population. In developing countries, food security depends greatly on the supply chain of fresh foods having distinct characteristics from other supply chains (Aragrande and Argenti, 2001; Poulton et al., 2010): (1) A large number of small and fragmented producers rely on intermediation for market access: (2) In many cases, the product cannot be inventoried because refrigeration is expensive and not suitable for all products. (3) Information on real-time market prices does not exist. (4) Quality and prices vary from source to source. (5) A variety of trading channels exists, namely direct sales, auctions, intermediation, and contracts complicating aggregation and economies of scale. And (6) supply and demand are highly seasonal.

Intermediation distinguishes the supply of fresh foods in first world countries from developing countries. This has always seemed as “evil” and for a good reason: intermediation raises the prices without adding value to the product, significant losses occur due to handling/transport (Balaji and Arshinder, 2016), traceability disappears, and some intermediaries monopolize the trade with obvious consequences (Aysoy et al., 2015). However, several authors disagree with that belief: Gabre-Madhin (1999) claims that intermediation is critical to market performance as it circumvents the issue of long distance trade with unfamiliar partners; Abebe et al. (2016) point out that middlemen play an important role by linking farmers to traders in fragmented supply chains consisting of several stages. Rodríguez and Neira (2008) reached a similar conclusion studying the trade and transport of milk and rice in Peru.

Intermediation, in general, has received great attention from theoretical perspectives. Influential papers, such as those of Rubinstein and Wolinsky (1987), Biglaiser and Friedman (1999), Spulber (1996) and Hendershott and Zhang (2006), have shown that despite its dubious role, intermediation helps shorten negotiation times, matches customers with vendors, and reduces transaction costs. Major differences exist between intermediation (brokerage) as studied in the above papers and intermediation in the fresh food supply chain in developing countries. First, most brokers act as trade facilitators who charge a transaction fee but they do not own the product; intermediaries in the fresh food trade, purchase the product and re-sell it. Second, brokers match customers with vendors, not the case in the fresh food trade. And third, the brokerage has little to do with the social network, as opposed to the fresh food trade in developing countries.

Several empirical works have studied intermediation in food supply chains in developing countries in regard to competition effects and

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price transmission; examples include Osborne (2005), who studied the trade of staple grains in Ethiopia; Fafchamps and Hill (2005), who studied the trade of coffee in Uganda; Moser et al. (2009), who proposed a model for the rice trade in Madagascar; Aysoy et al. (2015), who investigated the impact of a policy reform in a fresh food supply chain essentially banning informal (but promoting formal) intermediation in a large central market in Turkey; and Abebe et al. (2016), who investigated the role of middlemen in the trade of potatoes in Ethiopia. The following conclusions result from the above papers: First, spatially fragmented markets, with high marketing costs, have imperfect competition and a large proportion of profits corresponds to arbitrage. Second, since low price transmission results from high intermediation cost, then technological change leading to cost reductions does not correspond to greater gains at the farmer level. And, third, trade with intermediaries does not solely dependent on price but on the "social network", on the availability of transportation and on the traded quantities.

The literature has reported several strategies to eliminate or to reduce intermediation in fresh food supply chains; among these, the so-called Short Food Supply Chain (SFSC) initiative (Aubry and Kebir, 2013; Lanfranchi and Giannetto, 2015) has been popular. SFSC seeks to bring agricultural foods directly from producers to farmers' markets and relies on a close relationship between producers and consumers, low transaction costs, and efficient and cheap transportation systems. Other strategies aim to eliminate informal intermediaries and use one or a few intermediaries or processors instead. Examples include the widely known case of e-Choupal in India (Anupindi and Sivakumar, 2007) where a large processor assisted a large number of independent farmers in planting, harvesting, transporting and trading of soy; the case of organic foods in Brazil (Blanc, 2009); the fruit and vegetables exports in Madagascar (Minten et al., 2009); and the pineapple industry in Kenya (Minot and Ngigi, 2004) to name a few. Other well-documented strategies include contract farming (Kirsten and Sartorius, 2002), vertical integration (Lindgreen et al., 2008) and cooperatives and farmers' associations (Kirsten and Sartorius, 2002).

While diagnostics of the problems of fresh food supply chains based on empirical evidence exist (Barrett et al., 2010; Osborne, 2005; Poulton et al., 2010), simulation and analytical models, helpful to explain the dynamics of the systems, are often missing (Barrett, 2008). Furthermore, few studies have focused on theoretical or conceptual aspects of the role of intermediaries in fresh food supply chains in developing countries.

Many policy makers have attempted to eradicate intermediation without a complete understanding of its dynamics. Their strategy usually mimics what has worked in other parts of the world without serious analyses (see the case study in Appendix A). For instance, in Latin America, SFSCs and other initiatives can face difficulties in implementation: a direct relationship between wholesalers and corner shop owners commonly occurs but never between farmers and consumers. Moreover, farmers rarely go to large cities to sell their products to consumers for a number of reasons, including high transport costs, no confidence in the dynamics of the trade, and little knowledge of the cities. On the one hand, intermediaries make up part of the social rural network, provide financial assistance and reach out to producers outside the main roads and collection centers (Abebe et al., 2016). These middlemen act not only as a "bridge" between farmers and wholesalers/retailers but also as an interface who knows both ends of the business. On the other hand, contracts with large companies, work only when sellers can guarantee uninterrupted supply and standard quality and these require technology and government intervention (Minot and Ngigi, 2004). This rarely happens with fresh fruit and vegetables for local consumption.

The contribution of this paper is the study of intermediation in the supply chain of fresh products from a Multi-Agent System (MAS) perspective and proposes complementing previous theoretical and empirical works bringing new insights to the role of intermediation, sometimes difficult to obtain with theoretical models (Barrett, 2008). A model that helps explore feasible alternatives of market operations should mimic relevant dynamic drivers, and not just resemble market-level implications of equilibrium solutions (North et al., 2010). Therefore, we advocate for and develop an individual-based computational modeling approach. This will be the topic of Section 2.

2. Multi-agent systems

Recent advances in computer simulation have provided better insight into complex processes in the social sciences. The MAS approach is appropriate for systems where interactions, rather than the centralized power of a single entity, define the behavior of the system itself. The main characteristics of agents include autonomy, social ability, reactivity and, proactivity. Autonomy means the capability to make self-oriented decisions; social ability relates to the inherent communication of the agents; reactivity involves the ability to adapt to a changing environment and proactivity equates to goal-oriented behavior. A multi-agent system comprises a collection of autonomous, goal oriented individuals who interact both among themselves and with the environment or outside world. Each agent has a behavior defining the actions it can take; this behavior involves three steps: Evaluation of both the agent status and the environment, (ii) make and execute a decision and (iii) evaluation of the action taken and adjustment of the decision rules according to the changes in the environment.

Agents typically cooperate with other agents having common goals and negotiate conflicting goals (Macal and North, 2007). Agents continuously learn, act under uncertainty and incomplete information, perform in dynamic scenarios and, as dynamic entities, they inductively reason from previous decisions. Reinforcement learning is one of the most prominent machine-learning technologies, due to its unsupervised learning structure and ability to continually learn, even in dynamic operating environments (Hwang et al., 2009). There are many variants of this mechanism such as accelerated learning (Bianchi et al., 2014) for single agents and multi-agent reinforcement and collective learning (Lopez-Guede et al., 2015; Zolfpour-Arokhlo et al., 2014).

Multi-agent simulation has increased interest in supply chains with decentralization and information asymmetry among its members, because traditional tools such as mathematical modeling and system dynamics, seem limited and often unrealistic in those situations (Macal and North, 2007). The original models of MAS in the supply chain arose to study the problem of coordination and integration. Several topics on supply chains where MAS models have been reported include supply chain configuration (Labarthe et al., 2007; Li et al., 2010); the study of cooperation and negotiation (Goel et al., 2005; Jain and Deshmukh, 2009; Meng et al., 2014); and sustainability of food supply chains (Ge et al., 2015; Krejci and Beamon, 2013). Few models investigate the fresh food supply chain with MAS. One of the few relevant papers is that of Widener et al. (2013) who studied policies for the distribution of agricultural products in the so-called food deserts.

Regarding trading mechanisms in multi-agent systems, the literature on MAS has reported simulations using several protocols including auctions (Moon et al., 2008; Wong and Fang, 2010), contracts (Mohebbi and Li, 2012) and bargaining (Mármol et al., 2007; Ren and Zhang, 2014). In these cases, the agents set the negotiation objects (i.e. the products) and the deals (i.e., prices). In other market-based models, agents use auction-based protocols for negotiation, but the market sets the prices (Lee and Kim, 2008).

We present a computational model studying market-level effects of producers' and sellers' actions in a supply chain of fresh products. We construct an agent-based model using adaptive strategies (Ishibuchi et al., 2001), embodied by supply chain producers, to investigate several outcomes, such as prices, traded quantities and profit levels. Adaptive strategies occur in the context of repeated interaction (Kirman and Vriend, 2001) and under several interaction structures (i.e., with different degrees of intermediation). The model allows understanding