Market-level Effects of Firm-level Adaptation, Intermediation and Cost Heterogeneity 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 based competition in a multi-stage negotiation with both direct sales and intermediation, in the presence of cost-related heterogeneity at the agent level. Producers sell their products according to an adaptive Q-learning strategy. Product is sold to clients (small shops and consumers) according to two types of marketplaces, which are characterized depending on whether they obtain the product from intermediaries or directly from producers. The model is inspired by a networked market of perishable goods in Bogotá, Colombia. The results show that, contingent upon unit transportation cost and producers' learning rate, intermediation might lead to greater traded quantities than sales through direct marketplaces, although erosion of intermediaries' profits might also become compromised. Thus, we conclude that intermediation could serve as a mechanism for increasing market efficiency.

1. Introduction

In recent years, there has been growing worldwide interest on the supply chain of fresh products, given its importance for the urban population. Some of the most common characteristics in such supply chains are the huge losses of suitable foods for human consumption throughout the handling procedures and high levels of intermediation that increase the price of the product. This paper presents a computational model aimed to study market-level effects of producers' and sellers' strategies in a supply chain of fresh products. In principle, a socially desirable outcome might not only be reducing the role of intermediation, but also assuring an equitable participation of all involved actors, considering that these two concerns might be interdependent. A critical problem is the presence of a noticeable cost heterogeneity among producers, which makes economies of scale a factor of dominance in market operations and constitutes an impediment for small producers to access the market. Nonetheless, any proposed mechanism, while guarantying equal access, should not favor the small players to the point that their incentives to seek cost efficiency be eroded. Therefore, throughout the paper, we especially question if reducing intermediation is really desirable.

A proposed model that helps explore feasible alternatives of market operations should be able to mimic relevant dynamic drivers, and not just resemble market-level implications of equilibrium solutions (North et al., 2010) Therefore, we advocate for, and develop a so-called, individual-based computational modeling approach. The model aims to represent a set of interacting software agents, who would act on behalf of the users of the above-mentioned platform and would execute the market transactions. We present an agent-based model where several adaptive strategies (Ishibuchi, Sakamoto & Nakashima, 2001), embodied by the supply chain actors, are explored in order to understand implication on market outcomes (e.g., price and profit levels). Adaptive strategies are understood in the context of repeated interaction (Kirman & Friend, 2001) and under several interaction structures (i.e. with different degrees of intermediation). The model would allow understanding important tradeoffs between (i) access opportunities for producers and overall cost efficiency of the whole supply chain, and between (ii) considerations of different degrees of intermediation and feasibility of implementation of them. The model is inspired by a networked market in one of the poorest areas of Bogotá, Colombia, characterized by an active presence of intermediaries, and that possesses a recently inaugurated by a not-yet fully functional logistics platform (i.e. direct marketplace) that aims to counterbalance the effect of intermediation.

1.1. Background

Recent advances in Multi-Agent System (MAS) simulations have provided better insight of complex processes in social sciences. MAS are appropriate for systems where interactions, rather than the will of a single entity, define the behavior of the system itself. The main characteristics of agents are autonomy, social ability, reactivity and proactivity. Autonomy can be understood as the capability of making self-oriented decisions; social ability is related to the inherent communication of the agents; reactivity is the ability to adapt to changing environment and proactivity is defined as their goal oriented behavior. A multi-agent agent comprises a collection of autonomous, goal oriented individuals who interact among themselves and with the environment or outside world (Macal & North, 2007). Each agent acts based on its behavior (Macal & North, 2007) that can be summarized in 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 in the case of common goals and negotiate when there exist conflicting goals.

Other important issues related to MAS are: Continuous learning, acting under both uncertainty and incomplete information, and performing in a dynamic scenario (Macal & North, 2007). Multi-agent simulation has taken particular strength in supply chains with decentralization and information asymmetry among its members. This is mainly because the traditional models as discrete event simulation, mathematical modeling and system dynamics, are limited and often unrealistic in such situations (Macal & North, 2007). The original models of MAS in the supply chain were developed to study the problem of coordination and integration. These works are mainly focused on the importance of mitigating the impact of the demand variation amplification upstream the chain. This phenomenon is the well-known "bullwhip effect" (Moyaux, Chaib-draa & D'Amours, 2003; Ahn & Lee, 2004; Cao & Leggio, 2008). MAS models for supply chains in agriculture have been scarce. Such models have studied mainly problems of rural credit, crop selection, land use, natural resource management, and irrigation, to say a few (Barnauda, Bousquet & Trebuil, 2008.; Barreteau , Millier & Weber, 2004; Berger, Schreinemachers & Woelcke, 2006; Berger et al., 2007; Goel, Zobel & Jones, 2005; Schreinemachers & Berger, 2006).

Among the few projects involving MAS in agricultural supply chains, the CASA was one of the first (Gerber & Klusch, 2002). This project involved the application of MAS to support auctions, transportation, and other logistics services. Regarding multi-agent communication, the literature presents several protocols that include bidding (i.e., the contract net protocol), auctions (Wog & Fang, 2010), and bargaining (Fatima, Wooldridge & Jennings, 2004; Mármol, Monroy & Rubiales, 2007). In all these cases the negotiation objects (i.e. the products) and the deals (i.e., prices) are set by the agents themselves. In other mechanisms such as market-based models, agents use auction-based protocols for negotiation based on individual goals; prices however are set by the market (Lee & Kim, 2008).

1.2. The model

The general proposed model consists of five types of agents: producers, intermediaries, indirect marketplaces, direct marketplaces and buyers (small shops and consumers). Producers sell their products to the intermediaries or direct distributors; intermediaries buy from the producers and sell only to the indirect marketplaces which in turn sell to the buyers; direct marketplaces buy from the producers and sell to buyers.

1.2.1. Assumptions

We assume that (i) there is only one product to trade, (ii) all agents are located at predefined x, y locations, ((iii) in each round a producer sells its production to either one (and only one) intermediary or to one (only one) direct marketplace, whose trade price is set according to a demand function, (iv) in each round an intermediary sells all production he/she bought to one and only one indirect marketplace, whose trade price is set according to a demand function, (v) not only are producer's / buyer's decisions influenced by price, but also by distance, and (vi) the final price paid by buyers is a mark-up price.

1.2.2. Parameters

We define the following parameters: J = set of producers, I = set of intermediaries, R = set of direct marketplaces, W = set of indirect marketplaces, C = set of buyers, $d_{x,y}$ = distance between agent x and agent y, CT = cost of transport per unit of distance, CP_j = unit production cost of producer j, and q_j = quantity sold by producer j. We also make use of some coefficients to formulate the demand functions at the indirect and direct marketplace locations (a_1, a_2, a_3, b_1, b_2, and b_3). We assume two distinct ranges of values for CP_j, one for small producers and one for large producers, taking into account that small producers have higher production costs. Cost values are calibrated and drawn according to uniform distributions that are built according to producers' real data.

1.2.3. Variables

X_{ji} = binary variable that establishes if producer j sells to intermediary i

Y_{jr} = binary variable that establishes if producer j sells to direct marketplace r

Z_{iw} = binary variable that establishes if intermediary i sells to indirect marketplace w

Q_{Ii} = quantity bought by intermediary i (from a subset of producers)

Q_{Rr} = quantity bought by direct marketplace r (from a subset of producers)

Q_{Ww} = quantity bought by indirect marketplace w (from a subset of intermediaries)

U_{Jj} = profit of producer j

U_{Ii} = profit of intermediary i

U_{Rr} = profit of direct marketplace r

U_{Ww} = profit of indirect marketplace w

P_{Ii} = unit price paid by intermediary i (to all the producers he/she bought from)

P_{Rr} = unit price paid by direct marketplace r (to all the producers he/she bought from)

$P_{R'r}$ = unit price paid by buyers who bought from direct marketplace r

P_{Ww} = unit price paid by indirect marketplace w (to all the intermediaries he/she bought from)

$P_{W'w}$ = unit price paid by buyers who bought from indirect marketplace w

1.2.4. Equations

The following equations describe the trading process among producers, intermediaries, indirect marketplaces, direct marketplaces, and buyers. At every time step, each producer chooses either one intermediary or one direct marketplace:

$$\sum_i X_{ji} + \sum_k Y_{jk} = 1, \forall j \in J \tag{1}$$

Intermediaries sell to only one indirect marketplace:

$$\sum_w Z_{iw} = 1, \forall i \in I \tag{2}$$

Quantities bought by every intermediary i, every direct marketplace r and every indirect marketplace w are defined as $Q_{Ii} = \sum_j q_j X_{ji}$, $Q_{Rr} = \sum_j q_j Y_{jr}$, $Q_{Ww} = \sum_i Q_{Ii} Z_{iw}$, respectively. Profit calculations of producers, intermediaries, direct and indirect marketplaces are defined as follows:

$$U_{Jj} = (\sum_i P_{Ii} X_{ji} + \sum_r P_{Rr} Y_{jr} - CP_j)q_j - CT(\sum_i d_{ji} X_{ji} + \sum_r d_{jr} Y_{jr}), \forall j \in J, \tag{3}$$

$$U_{Ii} = (\sum_w P_{Ww} Z_{iw} - P_{Ii})Q_{Ii} - CT(\sum_w d_{iw} Z_{iw}), \forall i \in I, \tag{4}$$

For the sake of simplicity, we assume that indirect and direct marketplaces offer a price to buyers equal to a markup (m) over costs, $P_{W'w} = (1+m)P_{Ww}$ and $P_{R'r} = (1+m)P_{Rr}$, respectively. Every buyer k has a reservation price P_{ok}, so that it is a requirement that $P_{ok} > P_{W'w} + CTd_{kw}$ and $P_{ok} > P_{R'r} + CTd_{kr}$, $\forall k$, in order to have buyers participating. If indirect and direct marketplaces manage to sell everything they have bought, their utility values would be computed according to the following equations:

$$U_{Rr} = (P_{R'r} - P_{Rr})Q_{Rr}, \forall r \in R, \tag{5}$$

$$U_{Ww} = (P_{W'w} - P_{Ww})Q_{Ww}, \forall w \in W. \tag{6}$$

However, such utility computations depend on comparisons with the reservation price of each buyer, reason why traded quantities might be lower than Q_{Rr} and Q_{Ww} at every time step. Thus, given the nature of perishable goods, we do not assume the existence of inventories, which consequently implies that non-sold product is lost (while cost of it is borne). We also assume that both producers and buyers follow an adaptive rule to select where to sell or where to buy. Producers use a Q-learning adaptive rule that allow them to reinforce their choosing of intermediary / direct marketplace according to perceived positive profits in previous rounds. At every time t, every producer keeps a tracking score labeled Q_c, $c \in I \cup R$ (Ishibuchi, Sakamoto & Nakashima, 2001) and decides to update its choosing of intermediary or direct marketplace according to the following probability:

$$P(X' = c) = \frac{Q_{c,t} - min_{x \in I \cup R}\{Q_{x,t}\}}{\sum_{x \in I \cup R}(Q_{c,t} - min_{x \in I \cup R}\{Q_{x,t}\})}. \quad (7)$$

Q-related values are updated according to a learning rate that assimilates new information, α, so that $Q_{c,t} = (1 - \alpha)Q_{c,t-1} + \alpha U_{Jj}$ if $X_{ji} = 1$, and $Q_{c,t} = Q_{c,t-1}$ if $X_{ji} = 0$. Similarly, buyers update their Q-related tracking scores of indirect and direct marketplaces. However, following the Bogotá case, we assume the existence of only one indirect marketplace and only one direct marketplace, and that buyers only buy one unit every time step. Given such a binary choice for buyers, we set their tracking scores as $Q_{m,t}$, $m = \{\text{indirect}, \text{direct}\}$, according to $Q_{indirect,t} = (1 - \alpha)Q_{indirect,t-1} + \alpha(P_{ok} - P_{W'w} - CTd_{k,indirect})$ if buyer k buys from the indirect marketplace (otherwise $Q_{indirect,t} = Q_{indirect,t-1}$), and $Q_{direct,t} = (1 - \alpha)Q_{direct,t-1} + \alpha(P_{ok} - P_{R'r} - CTd_{k,direct})$ if buyer k buys from the direct marketplace (otherwise $Q_{direct,t} = Q_{direct,t-1}$). Thus, given such a binary choice, the probabilities to buy from the indirect marketplace and from the direct marketplace are computed as $Q_{indirect,t}/\sum_m Q_{m,t}$ and $Q_{indirect,t}/\sum_m Q_{m,t}$, respectively.

Prices at the intermediary, indirect and direct marketplaces are set according to linear demand functions:

$$P_{Ii} = a_i - b_i Q_{Ii}, \forall i \ \in I, \quad (8)$$

$$P_{Ww} = a_2 - b_2 Q_{Ww}, \forall w \ \in W, \quad (9)$$

$$P_{Rr} = a_3 - b_3 Q_{Rr}, \forall r \in R. \quad (10)$$

Coefficients b_1 , b_2 and b_3 are set so that prices become zero when demand is maximum (i.e., when demand is equal to $\sum_j q_j$). For the sake of simplicity, we also assume producers produce one unit of production every time step, so that $q_j = 1, \forall j$.

1.3. Background context

The modeled situation resembles the fresh food supply chain of Bogotá (Colombia) in which farmers sell their products to intermediaries who in turn re-sell the product throughout the city. There are several intermediation channels such as wholesalers, direct sales, small shops, etc. where the product is sold to the final customer. However, most of the trade of agricultural products is done through Corabastos, the largest wholesaler in Bogotá, which is responsible for supplying the capital and much of the country. The food prices there set the standards for trade nationwide. Intermediation levels are dissimilar but on average the overall price increase is around 65 %. Due to these high prices, end consumers have fewer opportunities to access quality foods, especially in some marginal populations of Bogotá.

To deal with such problems, the Mayor of Bogotá, implemented the Master Supply and Food Security Plan (PMASAB in Spanish) back in 2007, attempting a progressive transformation of the food supply system in the capital to ensure timely and uninterrupted availability of quality at fair prices. A key point of the plan was the establishment of "Agri-networks" (a network of farmers that organize food supplies in and out of its territory by integrating the management of agricultural, livestock, and fish products to consolidate production) and "Nutri-networks" (network of small shop owners) whose objective is the generation of collective efficiencies in the supply chain. Collective efficiency of both Agri and Nutri-networks, in theory, would theoretically achieve improvements in transportation, quality, packaging, and generate economies of scale to ensure their competitiveness and sustainability. The trade between Agri and Nutri networks would be accomplished thorough logistics platforms strategically located in the boundaries of the city. These two networks would be linked through Internet thus facilitating order placements and payments.

1.4. Summary of results

Snapshots of the model are illustrated in figure 1.

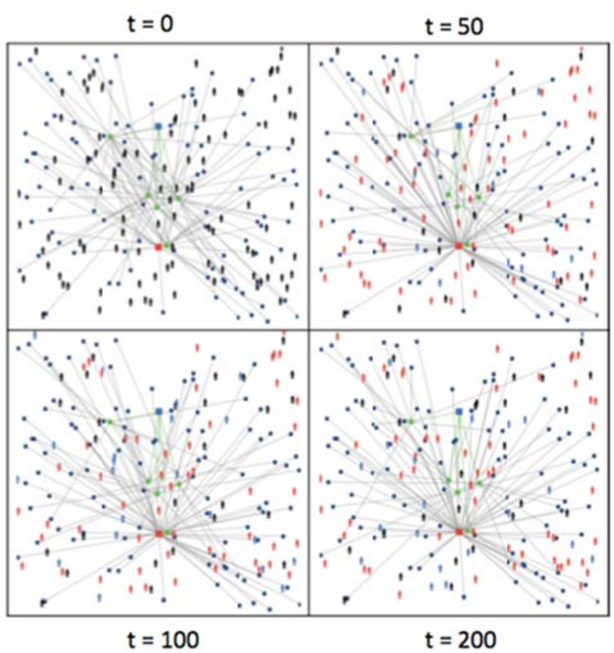

Figure 1. Sample snapshots that illustrate the market dynamics. The blue and red squares located in the middle represent indirect and direct marketplace agents. Green dots represent intermediaries. Connecting (blue) dots to either intermediaries or the direct marketplace represent producers. Such connections

establish who producers trade with. Unconnected agents (in blue, red, and black) are buyers. Black-colored buyers are not able to buy since their reservation price requirement is not met. Red buyers buy from the direct marketplace, while blues ones buy from the indirect marketplace. Producers and buyers update their choosing according to expectations based on past trading experience, which is controlled by the Q-related scores.

Producers chose either one of the intermediaries or the direct marketplace as trading partner. After profits have been realized, producers update their Q-related scores and decide the next trading partner according to the probability distribution generated by the Q-learning algorithm. Buyers behave in a rather similar fashion with regard to deciding whether to buy from the indirect or the direct marketplace (recall that, unlike producers, buyers face a binary choice). Profits of intermediaries and producers depend on distance costs and market prices.

Figure 2 illustrates average indirect and direct marketplace prices according to variations in the number of intermediaries (1, 5, 10) and the unit distance cost (0.01, 0.05, 0.10), assuming a mid-value learning rate $\alpha = 0.5$. We also assume values for a_1 , a_2, and a_3 to ensure that intermediaries' profits are positive ($a_1 = 5, a_2 = 15,$ and $a_3 = a_2$). In the presence of one single intermediary, prices are not significantly affected when the unit distance cost increases. However, increasing the number of intermediaries does reflect an effect of unit distance cost variations: A high unit distance cost and a high number of intermediaries forces the indirect marketplace price to be lower than the direct marketplace price, thus increasing attractiveness of buyers to buy from the indirect marketplace (recall that both indirect and direct marketplaces charge a markup over costs to buyers). In the presence of high transportation costs, intermediation plays a moderating role in relative price reduction in favor of the indirect marketplace.

Result 1: An increase of the number of intermediaries generates an indirect marketplace price relatively lower than a direct marketplace price, as long as unit transportation cost is high. This result implies that intermediation might increase market efficiency.

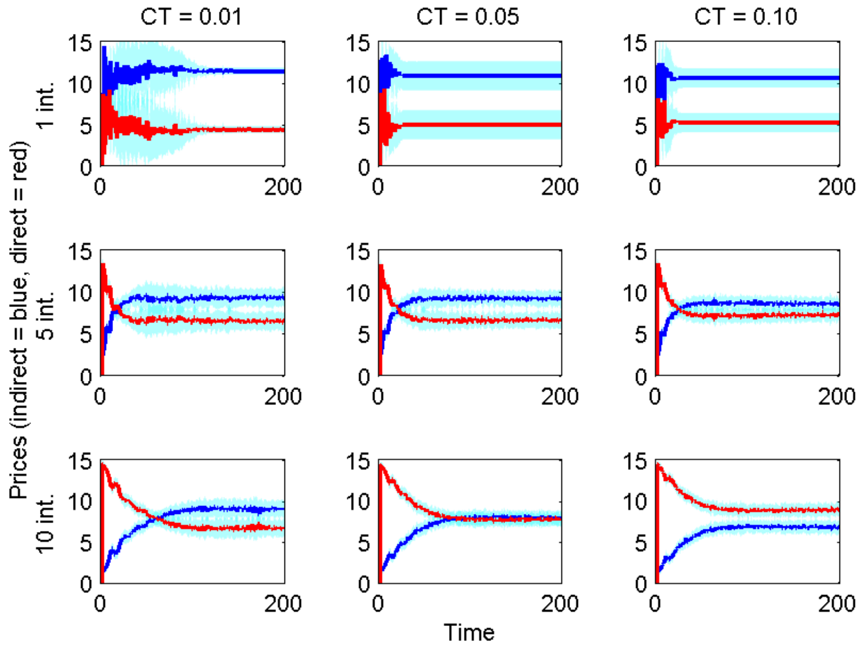

Figure 2. Average behavior of indirect and direct marketplace trading prices, $P_{Ww}$and P_{Rr} respectively, according to variations in the number of intermediaries and the cost of transport per unit of distance *CT*. Cyan shadows represent a one standard variation.

Figure 3 depicts the average behavior of intermediaries' profits at time *t*. Despite the effects of increasing unit distance cost on the price intermediaries pay, unit distance cost alone appear to have no negative effect on their profits. Instead, the presence of additional intermediary agents heavily (and negatively) affects their profits.

Result 2: Increases of unit transportation cost alone have no significant effect on intermediaries' performance, but increases of the size of the intermediary agent population negatively do.

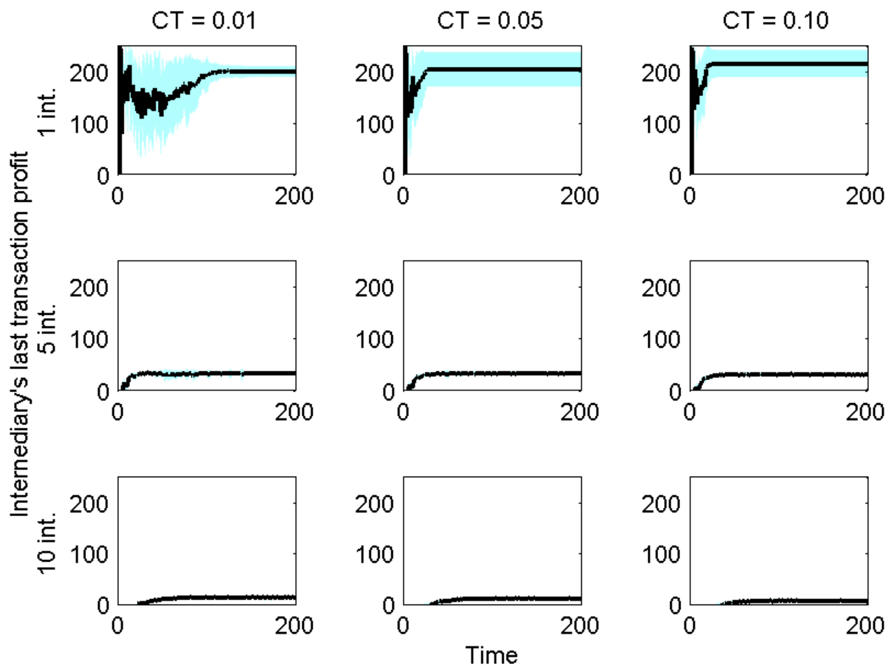

Figure 3. Average behavior of intermediaries' most recent transaction profits according to variations in the number of intermediaries and the cost of transport per unit of distance *CT*. Cyan shadows represent a one standard variation.

Also, both the increase in unit transportation cost and the number of intermediaries have an effect on indirect and direct marketplace quantities sold to buyers. Consistently with what was observed in Figure 2, buyers decisively lean toward the indirect market when both the intermediary population and the unit transportation cost are high. Market sizes also tend to be more balanced when both unit transportation cost and intermediary population are large, with respect to the case when both are small. See Figure 4.

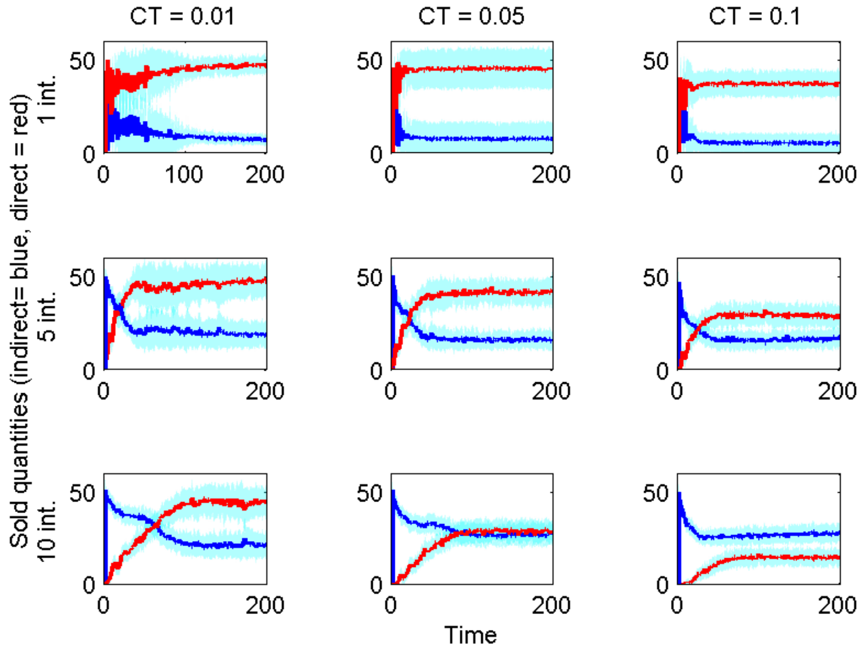

Figure 4. Average behavior of indirect and direct marketplace sold quantities to buyers, according to variations in the number of intermediaries and the cost of transport per unit of distance *CT*. Cyan shadows represent a one standard variation.

A different set of scenarios was explored by changing the value of the Q-related updating coefficient α (the learning rate). For that, we maintain a constant unit transportation cost of 0.05. Figure 5 illustrates that a higher adaptive capacity of producers (i.e. a higher value of α) coupled with a large intermediary population makes sales to intermediation more attractive in terms of price, which means that producers' strategic response to spot market opportunities (either through intermediation or direct sale channels) also have an impact on indirect market size increase.

Result 3: An increase of producers' learning rate and the size of the intermediary population bring on a reduction of the indirect marketplace price and a subsequent (relative) increase of the indirect market size.

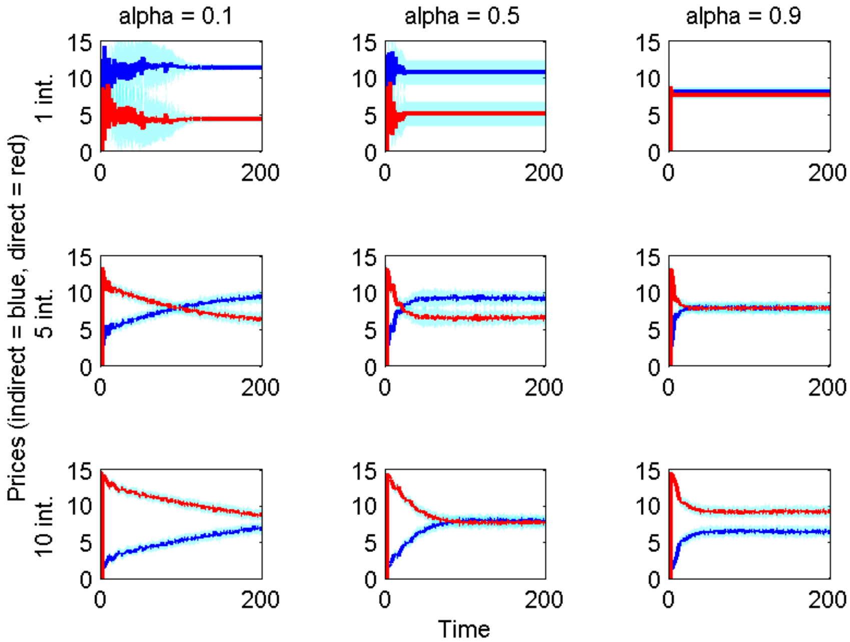

Figure 5. Average behavior of indirect and direct marketplace trading prices, $P_{Ww}$and P_{Rr} respectively, according to variations in the number of intermediaries and the learning rate (α). Cyan shadows represent a one standard variation.

1.5. Concluding remarks

Networked markets are complex systems where important trade-offs need to be inspected under the consideration of several contingent factors. Here, we have explored a simple model inspired by a case study of a perishable good (fresh food) supply chain in Bogotá, Colombia. Importantly, the model shows the important role of intermediation in influencing prices, contingent on factors like transportation costs and producers' ability to strategically manage market alternatives.

Results also suggest that, when transportation unit cost is high, small producers face a huge disadvantage to trade their products, which might place intermediaries as important actors in balancing trading opportunities between large and small producers. A simple way to inspect this is comparing the last (i.e. long-run) transaction profit distribution for both large and small producers (See Figures 6 and 7). Although it appears that not all small producers are benefited, some of them increase their profitability in the presence of a higher intermediary group.

The bottom line is, intermediation might play a significant role in the presence of high transportation costs since they partly absorb such costs, which might grant market access to small producers. Although other aspects of intermediation not considered here might dilute the benefits (e.g. market power through access), the presence of an intermediary set of market actors might be an important factor to guarantee market access to a larger fraction of the small players.

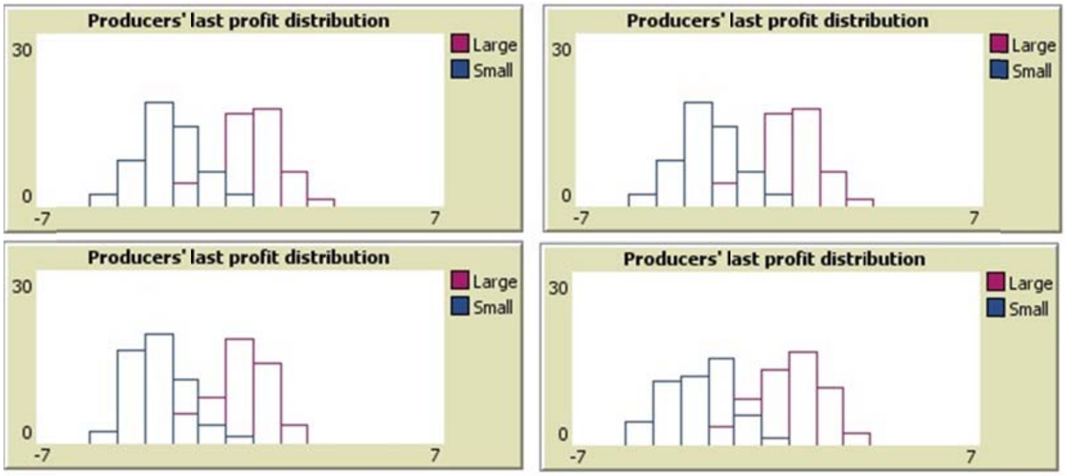

Figure 6. Sample outputs of last transaction profit distribution among all producers (large and small) in the presence of one intermediary

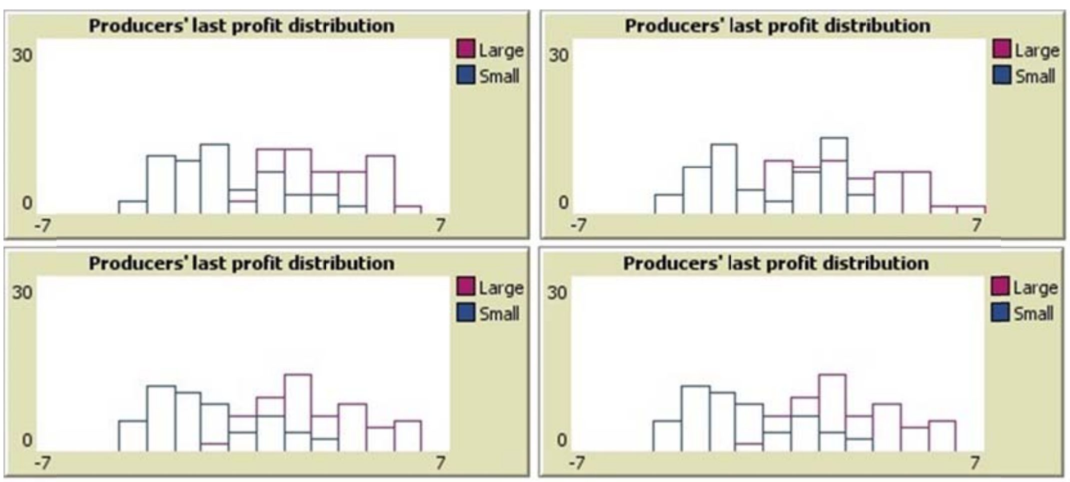

Figure 7. Sample outputs of last transaction profit distribution among all producers (large and small) in the presence of ten intermediaries

References

Ahn, H. J. & Lee, H. 2004. An agent-based dynamic information network for supply chain management. *BT Technology Journal*, 22: 18–27

Barnauda, C., Bousquet, F. & Trebuil, G. 2008. Multi-agent simulations to explore rules for rural credit in a highland farming community of northern Thailand. *Ecological Economics*, 66(4): 615–627

Barreteau, O., F, B., Millier, C. & Weber, J. 2004. Suitability of multi-agent simulations to study irrigated system viability: application to case studies in the Senegal

river valley. *Agricultural Systems*, 80: 255–275.
Berger, T. 2001**.** Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics*, 25: 245–260.
Berger, T., Birner, R., Mccarthy, N., Díaz, J. & Wittmer, H. 2007. Capturing the complexity of water uses and water users within a multi-agent framework*. Water Resources Management*, 21: 129–148.
Berger, T., Schreinemachers, P. & Woelcke, J. 2006. Multi-agent simulation for the targeting of development policies in less-favored areas. *Agricultural Systems*, 88: l28–43.
Cao, Q. & Leggio, K. 2008. Alleviating the bullwhip effect in supply chain management using the multi-agent approach: an empirical study. *International Journal of Computer Applications in Technology*, 31: 225–237.
Fatima, S., Wooldridge, M. & Jennings, N. 2004. An agenda based framework for multi-issue negotiation. *Artificial Intelligence*, 152(1): 1–45.
Gerber, A. & Klusch, M. 2002. Agent-based integrated services for timber production and sales. *IEEE Intelligent Systems*, 17, 33–39.
Goel, A., Zobel, C. & Jones, E. 2005. Multi-agent system for supporting the electronic contracting of food grains. *Computers and Electronics in Agriculture*, 48: 123–137.
Ishibuchi, H., Sakamoto, R. & Nakashima, T. 2001. Evolution of unplanned coordination in a market selection game. *IEEE Transactions on Evolutionary Computation*, 5(5): 524–534.
Kirman, A. & Vriend, N. 2001. Evolving market structure: an ace model of price dispersion and loyalty. *Journal of Economic Dynamics and Control*, 25: 459–502 (2001)
Lee, J. & Kim, C. 2008. Multi-agent systems applications in manufacturing systems and supply chain management: a review paper. *International Journal of Production Research*, 46(1): 233–265.
Macal, C. & North, M. 2007. *Agent-based modeling and simulation: Desktop ABMS.* Proceedings of the 2007 Winter Simulation Conference, pp. 95-106. Washington D.C.
Mármol, A., Monroy, L. & Rubiales, V. 2007. An equitable solution for multi-criteria bargaining games. *European Journal of Operational Research*, 177(3): 1523–1534.
Moyaux, T., Chaib-draa, B. & D'Amours, S. 2003. *Multi-agent coordination based on tokens: reduction of the bullwhip effect in a forest supply chain*, International Conference on Autonomous Agents, pp. 670–676. Melbourne, Australia.
North, M.J., Macal, C.M., Aubin, J.S., Thimmapuram, P., Bragen, M. & Hampton, D. 2010. Multiscale agent-based consumer market modeling. *Complexity*, 15(5): 37–47.
Schreinemachers, P. & Berger, T. 2006. Land use decisions in developing countries and their representation in multi-agent systems. *Journal of Land Use Science*, 1: 29–44.
Wog, T. & Fang, F. 2010. A multi-agent protocol for multilateral negotiations in supply chain management. *International Journal of Production Research*, 48(1): 271–299.