Markets as communication systems: simulating and assessing the performance of market networks

Franck Galtier, François Bousquet, Martine Antona, Pierre Bommel

Markets as communication systems

Franck Galtier
François Bousquet
Martine Antona
Pierre Bommel

1. INTRODUCTION *

The decisive role of markets in the dissemination of information among economic agents is now firmly anchored in the economic literature. Indeed, the dispersion of information relative to endowments, costs and preferences may make resource allocation inefficient (Hayek, 1937; Hurwicz, 1969; Grossman and Stiglitz, 1976; Smith, 1982). By chance, markets play the role of communication systems (Hayek, 1945; Radner, 1968; Hurwicz, 1969; Grossman and Stiglitz, 1976; Smith, 1982; Grossman, 1989; Kirzner, 1992). Agents reveal their private information through their trading behavior (search, offers, bids etc.). This information is aggregated in prices and other market signals, what leads to a dissemination of information inside the economic system. However, as the economic agents possess partial or even erroneous information, they are likely to behave in a way which leads others into error, and this can generate a cascade of misleading information running through the market. Hence there is no guarantee that the market process will converge towards efficient resource allocation (Hayek, 1937).

It is also well-known that markets are institutions: trading behaviors must follow established rules specifying "who can trade with whom" and how the parameters of the transaction (quantity, quality, and price) are measured and negotiated. These rules determine the performance of markets as communication systems and allocation mechanisms (Hayek, 1948; Smith et al., 1982; Grossman, 1989; Kirzner, 1997; Roth and Peranson, 1999).

Market rules can be translated in the concepts of information and communication theory (Galtier 2002b). The rules for measuring and negotiating the different trading parameters (quantity, quality, and price) constitute the *language of the market*. The messages sent by the agents in the form of offers and bids are expressed in this language. Market language affects the (unbiased and noiseless) revelation of agents' private information regarding their costs, endowments, and preferences. The rules that determine "who can trade with whom" constitute *the communication network of the market (or "market network")*[1]. Given that information is

[1] In the economic literature, networks are sometimes presented as coordination mechanisms alternative to markets and hierarchies. Another approach (more fruitful in our view) considers that the network topology is an attribute of all institutions (markets, hierarchies and others). The network gives the set of all possible interactions between the agents involved in an institution. This approach has led to two strands of literature. The first analyzes the performance of network topologies without specifying the institution shaped by the network (e.g. Jackson, 2003). The second deals with the performance of network topologies for specific institutions such as the firm (e.g. Aoki 1986) or the market (e.g. Smith 1982; Ioannides 1997). The present article belongs to the last category.

* We thank Alan Kirman for valuable comments on an earlier draft and the two referees of the review for very interesting comments and suggestions.
Correspondence to: F. Galtier

disseminated through negotiation and transaction behaviors, the market network defines the channels through which information flows.

As Kirman (1987) emphasized, almost all the literature on market networks focused on two types of communication networks: Walrasian star-shaped networks and complete networks. In *Walrasian star-shaped networks*, each agent is only connected to a central auctioneer (Hurwicz, 1969; Radner, 1972; Grossman and Stiglitz, 1980). This is typical of a completely centralized market. Those studies have been criticized by Austrian School economists for their lack of realism: they failed to capture the real (decentralized) nature of markets (Hayek, 1948; Thomsen, 1992; Kirzner, 1992, 1997). In *complete networks*, each agent is connected to all others. This is typical of a completely decentralized market (Feldman, 1973; Ioannides, 1975; Smith, 1982; Hardle and Kirman, 1995 ; Schnabl, 1996; Roth and Xing, 1997; Kirman and Vriend, 2000; Weisbuch et al., 2000; Kirman et al., 2005). Most studies converge to the general result that decentralized markets with a complete network are efficient.

However, many real markets are decentralized and have an incomplete communication network (Kirman, 1997; Potts, 2001)[2]. Can they lead nevertheless to an efficient allocation? There are two different ways to tackle this question: to study general properties networks should have in order to be efficient, or to study the performance of specific topologies of networks. The first approach (which often employs game theory) was developed during the 2000s (Kranton and Minehart, 2001; Jackson 2003; Corominas-Bosch, 2004; Ozsoylev, 2005; Bramoullé and Kranton, 2007; Evstigneev and Taksar, 2008; Bloch et al., 2008). Some results of these researches can be drawn. First, efficient networks are in general regular networks (with a quite similar number of connections for each agent). Second, the degree of connection inside the network has usually a positive impact on efficiency[3]. Third, efficient networks can hardly emerge because of positive network externalities (stable networks are usually underconnected) except in some very specific situations (very low link costs, specific price-fixing mechanisms etc.). In line with the second approach, some studies have focused on networks with a specific topology, such as circular networks (Jovanovic, 1987; Ioannides, 1997), lattice networks (Föllmer, 1974; Durlauf, 1994) or trading groups (Ioannides, 1990). These researches are less generic than those of the first approach (because they focus on a specific network topology) but they give a better assessment of the performance (because they are able to measure the distance to the optimum and, by so doing, are able to compare the performance of non optimum networks). Moreover, new mathematical, computational, and experimental tools available to the study of markets (Roth, 2001) make it possible now to analyze markets with much more complex (and realistic) communication networks.

The main objective of this article is to assess and to compare the performance of two widely used market (incomplete) networks: network trading and marketplace trading. *By the assessment of their performance, we want to test Kirzner's conjecture*. Kirzner's conjecture is that decentralized markets can be very efficient, although they disseminate far fewer bits of information than centralized Walrasian markets (Kirzner, 1992). If decentralized market institutions such as network trading and marketplace trading prove to have a performance

---

[2] According to Jack Birner, it was also the point of view of Hayek who first brought to the fore that markets are communication systems: "[W]hat Hayek presents is a network theory of markets in which connectivity, frequency and strength of interactions, the establishing of new relations and the transmission of new information are central features" (Birner, 1999, p. 40).

[3] Except when the network plays the role of both a transaction network and an information network on unreliable agents (Bloch et al. 2008). In this case, a U-shaped curve was found: stability is linked to low and high degrees of connection, whereas networks of intermediate density are unstable.

level closed to the optimum, it would be a strong argument in favor of Kirzner's conjecture. *By the comparison of their performance, we want to test the very widespread preconception that marketplace trading leads to more transparency and a better allocation of resources than network trading*. Indeed, there is a large consensus among researchers about the superiority of marketplace trading in terms of information dissemination and resource allocation. Even the defenders of network trading (who highlight the fact that networks permit a reduction of transaction costs and a better access to credit), agree that, in terms of information dissemination, marketplace trading always performs better (Granovetter, 1985; Grégoire, 1986; Fafchamps and Minten, 2001).This idea has major implications for market design. Indeed, in developing countries, states and funding agencies tend to favor marketplace trading, judged to be better for market transparency, competition, and allocation of resources[4]. We want to test whether marketplace trading is always better than network trading and, if not, to determine in which type of environment each institution is better. We also want to analyze the way in which the main characteristics of the environment influence the performance of each institution.

To do this, we developed a multi-agent model (called *Markets)* and performed 1,800,000 simulations. Our work was based on the example of cereal trading in West Africa, a case in which both institutions co-exist (Galtier, 2002 a). Empirical data were used to give a stylized description of marketplace trading and network trading, to calibrate some of the parameters of the model, and to confront the results of the model with reality. These simulations showed that while network trading and marketplace trading disseminate far fewer bits of information than a perfectly transparent market, they manage to generate an allocation of resources that is almost as good. In many cases, network trading proves more effective than marketplace trading (contrary to a very common preconception). This surprising performance of network trading is linked to a form of indirect arbitrage induced by connections between networks.

First, we will present a stylized description of the functioning of marketplace trading and network trading. This will lead us to formulate hypotheses about the influence of the environment on the comparative performance of these institutions and to present a methodology to test them. Then, we will present the model, the simulations performed, the results and a discussion (including implications for market design and public policy making). We will conclude with some comments on the relevance of the tool used, on the more interesting results and on the new research avenues opened up by this work.

2. MARKETPLACE TRADING VERSUS NETWORK TRADING

The market network of network trading is very different from the one of marketplace trading. Network trading is based on a fixed network (trading relations are based on long-term personalized relationships), whereas marketplace trading generates a changing network (which may be random) depending of the movement of the traders from one marketplace to the next. Moreover, network trading is based on bilateral trade (each trader negotiates separately with the different traders), whereas marketplace trading functions with multilateral trade. In the literature, an interesting in-between case can be found: a network characterized by multilateral trade within a fixed network (Kranton and Minehart, 2001).

[4] Aid agencies have funded the construction of numerous wholesale markets in African countries.

2.1. Empirical context

Network trading and marketplace trading are two modes of organizing wholesale trade. In many market chains, the organization of wholesale trade is crucial, since large-scale transfers between surplus and deficit zones depend upon the links that exist between wholesalers in the production zones and those in consumption centers. Network trading is widely used by the Chinese and Lebanese diasporas for their international trade in manufactured products (Granovetter, 1994). It is also widespread in West Africa, notably in the Sahel region, for local or regional trade in agricultural products (Grégoire, 1986; Lambert and Egg, 1994). This mode of organization, doubtless inherited from trans-Saharan trade, dates back at least to the 14th Century (Amselle, 1977; Grégoire, 1986). Marketplace trading is, for its part, widely used for agricultural products all over the world. In marketplaces of developing countries, transactions are often negotiated by bilateral trade, while in other regions of the world, auction markets are found. In the case of agricultural products, both network trading and marketplace trading serve to connect wholesalers located in production zones with those living in urban consumption centers. In both cases, production zones wholesalers (PWs) collect the product from producers in villages and store it in their warehouses (located in small provincial towns). Consumption zone wholesalers (CWs) obtain their supplies from PWs and sell the product to urban retailers and consumers. The case of cereal trading in West Africa is very interesting as both institutions co-exist in this region. While network trading prevails in Mali (and in the other Sahel countries), marketplace trading is dominant in Benin and in other coastal countries (Galtier, 2002a).

2.2 Stylized description of marketplace trading and network trading

To understand better the performance of marketplace trading and network trading, we have to analyze the functioning of theses two institutions, especially the topology of their market network.

Marketplace trading

If several studies exist about what occurs inside a marketplace, there are very few works on the functioning of systems of interconnected marketplaces. Spatial integration analyses have been applied to many types of markets including marketplace trading. (For the specific case of the Benin maize market, see Kuiper et al., 2003.) The studies of this type focus on the level and velocity of the transmission of price changes among different places. But, as the market process is studied only through prices, it is often difficult to explain observed differences in the transmission of price movements. To understand better the dissemination of information and the allocation of resources, it is necessary to open the black box of the functioning of the market with its rules and their impact on the sellers and buyers' behaviors and interactions. More interesting for us is the work of Yannis Ioannides (1990) on trading groups. The system analyzed by Ioannides is very similar to marketplace trading in the sense that the agents form different sub-markets inside of which occurs multilateral trade. The main difference is that, in marketplace trading, only the buyers move among sub-markets (the sellers pertain to one sub-market). Another difference is that, in the model of Ioannides, the agents do not choose a sub-market, but rather choose the number of agents with whom they wish to be connected and this determines the formation of the sub-markets (trading groups). However, it will be interesting to compare the results of Ioannides with our own results on marketplace trading.

The functioning of marketplace trading is very simple. Consumption localities wholesalers (CWs) travel around the production zones, where they meet production zones wholesalers (PWs) at marketplaces (on market day). The marketplaces, which generally function on a weekly basis, bring together all the PWs in the zone and CWs from various deficit zones of the country. If one tries to understand better the implications of marketplace trading for information dissemination, two questions arise:

- *How do the CWs choose the marketplace to which they go?* From a theoretical point of view, there is no optimal behavior. If the market price was low on the previous market day, it may be interpreted as a sign of unsold stocks and attract CWs. But such a rush on the following market day may induce a surge in prices. From an empirical point of view, it depends. In the Benin cereal market, empirical surveys have shown that the CWs almost always choose randomly the production zone to which they go (Galtier, 2002a). The CWs explained their behavior by the instability of prices, the last price on a marketplace leading to misleading expectations of the next price.

- *What occurs within marketplaces in terms of dissemination of information?* It is generally assumed that the low search costs and the publicity of negotiation permit an aggregation of all the information held by the buyers and sellers present in a marketplace (transparency). However, this idea has been challenged by an empirical and computational study based on the case of the Marseille fish market (Kirman and Vriend, 2000). This study shows that, under certain circumstances, there is no complete price levelling nor aggregation of information. Another study based on the modelling of learning behaviors shows the same result, but in a completely different way (Brenner, 1997).

Network trading

Most of the studies on network trading have been performed by sociologists or anthropologists, both at the international (Granovetter, 1985, 1994) and west-African levels (Amselle, 1977; Grégoire, 1986; Lambert and Egg, 1994). They have highlighted the fact that networks founded on lasting relations of fidelity based on trust permit transactions at a distance (by phone), thus avoiding the need for expensive travel, and facilitate credit transactions. Most of economists have followed the same line, arguing that trade networks permit the solution of problems of missing markets for credit (Fafchamps and Minten, 2001) and reduce transaction costs (Greif, 1989, 1993). However, analyses of the impact of network trading on information dissemination and resource allocation are less common and relatively recent. Some authors have examined the respective roles of Sahelian trade networks and public market information systems (MIS) in the dissemination of information inside the cereal markets (Egg et al., 1996). Others have attempted to link empirically the spatial structure of networks and the transmission of information on prices within the market (Hamadou, 1997). Lastly, Corominas-Bosch (2004) studied bilateral bargaining in trade networks. She focused on the decisive role of who starts to propose for network trading efficiency.

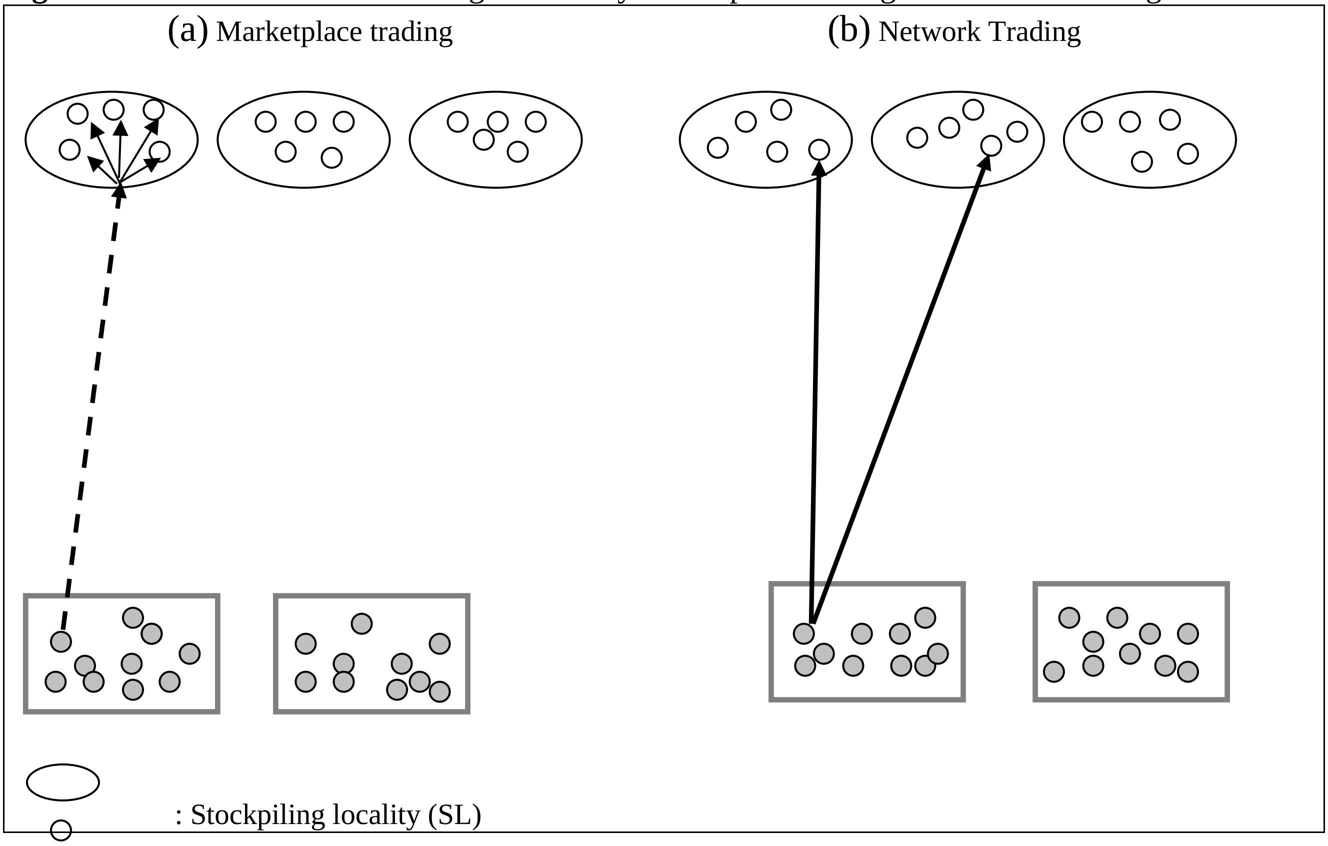
Using these different works, we can give a stylized description of the functioning of network trading. With this institution, the entire negotiation and exchange process takes place at a distance. Each wholesaler in a consumption zone (CW) has correspondents (PW) in the different production zones (one per zone) and, in principle, should only procure supplies from his correspondents. Thus, when a CW wishes to buy a product, he contacts his correspondents in different locations (usually by telephone, or by mail delivered by truckers or taxi drivers), centralizes the sale proposals made by each of them (in terms of price, quality, delivery date, terms of payment, etc.) and concludes a transaction with the one making the most attractive offer. Sometimes, the functioning of network trading is completed by two mechanisms of flexibility. First, CWs who have difficulties procuring supplies within their network can ask their correspondents to try and obtain them from other PWs in their locality. Second, PWs who have accumulated unsold stocks can take the initiative to contact their correspondents CWs.

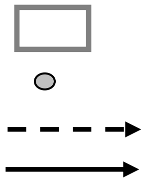
Marketplace trading versus network trading

There exists a very common preconception in favor of marketplace trading which is supposed to generate a high level of transparency. As we mentioned before, this preconception has induced public policies in developing countries, such as the design of marketplace trading institutions. However, to our knowledge, the unique study comparing the performance of network trading and marketplace trading in disseminating information and allocating resources is Galtier (2002a). This study was based on empirical data about two cereal markets of west-Africa: the Malian one (structured by network trading) and the Beninese one (based on marketplace trading). In this article, we choose a very different way to compare the performance on these two institutions: computer simulations. We will confront the results of the simulations with the results of the empirical study in the discussion.

What are the main differences in the functioning of marketplace trading and network trading? The two institutions differ mainly in their temporal and spatial aspects (Fig. 1). Indeed, in one case (network trading), the architecture of communication channels is stable over time, whereas in the other (marketplace trading), it is continuously changing, as the CWs move from one place to the next. The two institutions also differ in their spatial coverage. Network trading enables CWs to communicate (by telephone) with PWs in different production zones, but not to arbitrate between different PWs in the same zone. On the other hand, in marketplace trading, each CW can communicate at a given time with all the PWs in a single production zone (the one to which he has gone), but he cannot arbitrate between PWs from different zones.

Figure 1. Communication channels generated by marketplace trading and network trading





: Production zone wholesaler (PW)

: Consumption locality (CL)

: Consumption zone wholesaler (CW)

: Movements

: Communication

2.3. Hypotheses

An interesting subject deals with *the gap between the performance of network trading and marketplace trading*, on the one hand, *and a perfect allocation of resources*, on the other. The aim is to test Kirzner's conjecture that decentralized markets can be very efficient, although they disseminate far fewer bits of information than centralized markets (Kirzner, 1992). If network trading and marketplace trading prove to have a performance level closed to optimum, it would be a strong argument in favor of Kirzner's conjecture.

Another interesting question is linked to *the comparative performance of network trading and marketplace trading*. Which institution is the better one (in a given environment) for information dissemination and resource allocation? The stylized description of the functioning of theses two institutions shows that information dissemination is very different in the two cases (see section 2.2). Marketplace trading looks better for aggregating information within production zones, whereas network trading seems to be better for aggregating information from different production zones. This led us to the idea that the heterogeneity of the PWs' supplies *within each zone* should give the advantage to marketplace trading, whereas the heterogeneity of the PWs' supplies *between zones* should give the advantage to network trading. What determines the heterogeneity of the PWs' supplies within and between zones? Obviously, what matters is the variability of supply flows to PWs. This variability depends partly on factors linked to the PW, and, partly, on factors linked to the zone in which the PW operates. For instance, illness of a PW is a factor linked to the individual. By contrast, rainfall is a factor linked to the zone: it affects the supplies of all the PWs in the zone through their effects on the date and level of harvests and on the accessibility to the villages (flooded roads). We choose to call "I" the set of factors linked to the individual and "Z" the set of factors linked to the zone. Then, we can say that I determines the heterogeneity of the PWs' supplies *within zones*, whereas Z is the key determinant of the heterogeneity *between zones*. We can then formulate the following hypotheses about the influence of the environment on the comparative performance of marketplace trading and network trading:
H1: All other things being equal, I [set of individual factors that affect the supply to PWs] should give an advantage to marketplace trading
H2: All other things being equal, Z [set of factors linked to the zone that affect the supply to PWs] should give an advantage to network trading

The *number of PWs* (nbPW) may also play a role. Indeed, if a CW arbitrates between *n* PWs, what matters is the variability of the aggregated supply of these *n* PWs. This variability is reduced when *n* increases. Of course, the reduction impacts only the part of the variability which is not correlated between PWs. We will call this reduction of variability the « dilution effect ». In *marketplace trading*, each CW can arbitrate between all the PWs of a given stockpiling locality. So, when the number of PWs in the locality goes up, each CW arbitrates between more PWs, which increases the dilution of the variability of the supply with which he is faced. More exactly, what is reduced is the no-correlated part of the variability (the part due to I). *So, the more PWs in the locality, the stronger the dilution effect on the variability due to I*. In this article, we will assume that PWs are homogeneously distributed among stockpiling localities: the number of PWs in each locality is proportional to the total number of PWs (nbPW). So, nbPW should have a positive impact on the dilution effect and, by doing so, on marketplace trading performance. By contrast, in *network trading*, the number of PWs to which each CW is connected is independent of the total number of PWs (it depends on the number of stockpiling localities in which the CW has a correspondent). So, in the case of network trading, the total number of PWs should not induce a dilution effect on the variability of PWs' supplies. Nevertheless, nbPW may affect the performance of network trading in a different way. Indeed, in the network trading system, the connection between networks depends on nbPW. A high number of PWs means that each PW is in contact with fewer CWs. CWs have fewer common PWs suppliers which means fewer connections between CWs' supply networks. This may reduce the information dissemination among agents in the market and deteriorate the allocation of resources. So, we expect nbPW to have a positive impact on marketplace trading performance and a negative one on network trading performance. Both effects advocate for the hypothesis that nbPW should give the advantage to marketplace trading. We can then formulate the following hypotheses:

H3: All other things being equal, nbPW [number of PWs] should give an advantage to marketplace trading.

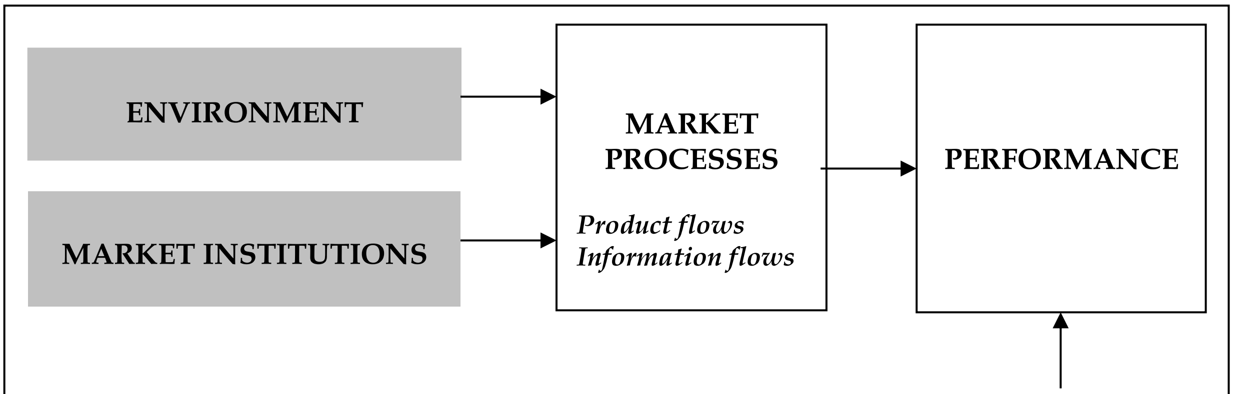
H3a: All other things being equal, nbPW [number of PWs] should have a positive impact on marketplace trading performance by diluting the effect of I [set of individual factors that affect the supply to PWs].

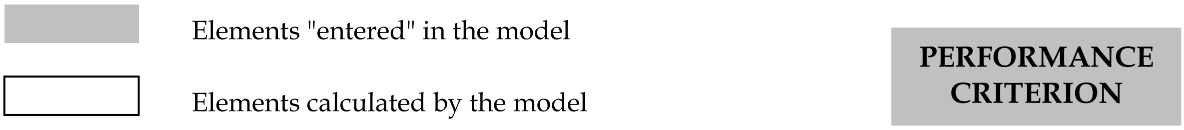
H3b: All other things being equal, nbPW [number of PWs] should have a negative impact on network trading performance by reducing the level of connections between CWs supply networks.

2.4. Methodology

To test these hypotheses, we used computer simulations of market processes. The approach consisted in "entering" an environment/market institution pair in the model, simulating the resulting market process and measuring the performance of the resource allocation thus obtained in accordance with a previously defined criterion. So, the model comprises three exogenous components (shown in Figure 2): environment, market institutions, and performance criterion. We will now give some details and justifications about the way we choose to represent these three components in the model Markets.

Figure 2. Methodology for computer simulation analysis





The *environment* is what determines the performance of a given institution. We see that those determinants may be the number of PWs and the factors affecting the variability of supply to PWs: nbPW, I, and Z. How could we represent I and Z in the model? A simple way was to represent them in the form of hazards affecting supply flows to production zone wholesalers (PWs). More precisely, at each time step, the supply to each PW must depend partly on a random factor linked to himself, and partly on a random factor linked to the zone in which he operates. The supply received by each PW at each step of time is a price/quantity pair. To keep the model simple, we assumed that only the quantity supplied to a PW depends on the random factors linked to the individual and to the zone. This simplification is not a problem because the performance criterion we used was exclusively based on quantities (see below). We assumed that, in the long run, supply equals demand. So, the expected value of quantity supplied to each PW should be independent of random factors and should be equal to the demand addressed to the PW. This last condition implies that expected value of overall supply should be equal to overall demand at each time step. We defined a formula for the random quantity supplied to the PWs that satisfies all these conditions:

$$qS = Ed\ (1 + HI\ i + HZ\ z) \qquad (1)$$

With:

qS: random quantity supplied to a PW

Ed: expected value of the demand addressed to the PW

HI: weight of the hazard linked to the individual

HZ: weight of the hazard linked to the zone

i, z: random variables that can take the values -1, 0, and 1 with equal probability. i and z are randomly determined at each time step for each PW (in the case of i) or each production zone (in the case of z).

It was then possible (depending on the values given to nbPW, HI and HZ) to generate a set of environments characterized by the number of PWs (nbPW) and the randomness of supplies to PWs linked to the individual (HI) and to the zone (HZ). Note that, as qS should not be negative, the condition E(qS) = Ed is satisfied only if $HI + HZ \leq 1$, which has some implications on the definition of the simulated scenarios.

The *market institutions* were represented in a stylized manner. The essence of *network trading* is the relation of fidelity between PWs and CWs which defines trading (and communication) channels that are fixed in time and allow the CWs to buy only from the PWs of their network. The essence of *marketplace trading* is the movement of CWs at each time step, and the transparency that prevails in each marketplace. In line with empirical observations in Benin, we assumed that the movement of CWs to the marketplaces is random. In order to be able to assess the *level of performance* of marketplace trading and network trading, we introduced into the model a benchmark perfect market institution, i.e. one allowing total market transparency and optimum resource allocation. As we assumed a total transparency at the level of marketplaces, such a benchmark institution can be modelled as a gigantic marketplace taking in all the PWs and CWs of the model. We therefore established three "sub-models" corresponding to three different market institutions: the benchmark institution (named "EXCHANGE"), marketplace trading ("PLACES") and network trading ("NETWORKS"). Last but not least, in each sub-model, *all information flows passed through negotiation and transaction behaviors*. Indeed, as we wanted to assess the performance of marketplace trading and network trading as communication systems, it was better not to include other type of communication in the model.

The performance of a market institution in a given environment is measured through the quality of the resource allocation it generates. Generally speaking, the most relevant *performance criterion* for assessing resource allocation is the welfare of the ultimate beneficiaries of trade, i.e. producers and consumers. However, in this study, we considered the case of a staple product (such as cereals in West Africa, which play a decisive role in food security because they provide most of the calorie intake of populations). This led us to focus ourselves exclusively on the welfare of consumers (consequently, producers are not represented in the model). This also led us to choose a definition of consumers' welfare based on the minimization of rationing, the rationing being defined by the consumers' unsatisfied demand for the product over a given period of time. So, it was possible to represent the consumers in an aggregated manner (through the consumption localities). As we considered a staple product, we assumed that demand is inelastic and constant over time. It was then possible to fix the cereal demand of consumers in each consumption locality and at the global level. (For the sake of simplicity, we assumed that each consumption locality had the same demand.) Consumers' rationing at each time step could then be measured at each consumption locality (CL), by resting the stocks of all the CWs of the CL on the demand of the CL. By summing the rationing of all CLs, we could calculate the global level of rationing generated by an institution X in a given environment over a given period of time. The performance of an institution X in an environment Y could then be defined by the following formula:

$$P\,[X\,;\,Y] = D - R\,[X\,;\,Y] \qquad (2)$$

With:
P [X , Y]: performance of institution X in environment Y
D: global demand of consumers
R [X ; Y]: aggregate rationing generated by institution X in environment Y

P [X ; Y] is an indicator which allows us to compare the performance of different institutions in the same environment (by varying X) or of an institution in different environments (by varying Y). It will then be very useful to compare the performance of marketplace trading and network trading in many environments. Note, however, that P [X ; Y] is in no way an indicator of *the level of performance* of the institution X in the environment Y. In fact, as PW supplies are random in the model, there is a non-negligible probability that, at certain times, the overall supply will be inferior to overall demand, which leads to consumer rationing. However, in this case, it is a physical imbalance between supply and demand, and not a problem of resource allocation. Optimum allocation of resources does not therefore correspond to zero rationing, but to the level of rationing generated by the benchmark institution EXCHANGE, which ensures a perfect match between total supply and total demand at each time step. More precisely, the optimum allocation of resources reachable in an environment Y is given by the following formula:

$$O\,[Y] = P\,[EXCHANGE\,;\,Y] \qquad (3)$$

With:
O [Y]: optimal resource allocation reachable in the environment Y

P [EXCHANGE ; Y]: performance of the sub model EXCHANGE in the environment Y

To measure *the level of performance* of the institution X in an environment Y, we have to consider only the part of the rationing which can be explained by failures in information dissemination and resource allocation, and ignore the part due to physical imbalance between supply and demand. These two effects can be separated by a comparison with the benchmark institution. More precisely, we defined the *level of performance* (LP) and the *relative level of performance* (RLP) of an institution X in an environment Y by the following formulas:

$$LP\ [X\ ;\ Y] = P\ [X\ ;\ Y] - O\ [Y] \quad (4)$$

$$RLP\ [X\ ;\ Y] = P\ [X\ ;\ Y]\ /\ O\ [Y] \quad (5)$$

With:
LP [X , Y]: level of performance of institution X in environment Y
RLP [X , Y]: relative level of performance of institution X in environment Y
P [X , Y]: performance of institution X in environment Y
O [Y]: optimal resource allocation reachable in the environment Y

3. DESCRIPTION OF THE MODEL

The structure of the model corresponds to a computer representation of the market institutions and of the environment in which they operate. Based on a scheme often used for multi-agent models, we divide the model description into three parts:
- Description of the entities representing the agents, their interactions and their environment
- Description of model dynamics
- Description of the indicators to be observed (model outputs)

3.1. Entities of the model

3.1.1 Spatial entities

The spatial entities represent the different localities in which PWs are based (stockpiling localities or SLs) and in which CWs are based (consumption localities or CLs). For the sake of simplicity, all SLs have the same number of PWs and all CLs have the same number of CWs. Some localities are marketplaces, where the supply and demand functions of the different agents present are able to be aggregated and matched. This is the case of the CLs in all the model scenarios and it is also the case of the SLs in the scenarios performed with the "PLACES" sub-model (representing marketplace trading). The production zones are assimilated to SLs: there is only one SL per zone and each SL corresponds to a zone. So, each SL is characterized by a random factor affecting the level of supplies to wholesalers (PWs) in the zone for each time step. This factor is equal to HZ z, HZ being an attribute of the SL class (HZ is equal for all SLs) and z being randomly determined at each time step for each SL (z can take the values -1, 0, and 1 with equal probability). The consumption localities (CL) are characterized by a product demand level dCL independent of price: dCL = D / nbCL, D being the global demand of all consumers and nbCL being the number of CLs. For the benchmark institution ("EXCHANGE" submodel), there is also another type of locality (called "exchange"): a big marketplace to which all the PWs and all the CWs are connected.

3.1.2 Agents

As the model represents wholesale transactions, the only agents included are wholesalers from production zones (PWs) and wholesalers from consumption zones (CWs), with the consumers represented in an aggregate form by the consumption localities. The wholesalers (both PWs and CWs) are defined by a certain number of common attributes: their name, locality, stock and supply function. The wholesalers' stock consists of a vector of price/quantity pairs, and the price assigned to the different quantities in store is their purchase price. As storage costs and profits are considered as nil in the model, the supply function of the wholesalers is easily calculated from their stock as a cumulative function of quantities. If the stock of a wholesaler w is represented by the formula: STOCKw= $\{(P1;Q1);(P2;Q2);...;(Pi;Qi);...;(Pn;Qn)\}$, then its supply function is given by SUPPLYw(Pj)= $\sum_{i=1}^{i=n}(Qi * Ai,j)$ where Ai,j = 0 if Pi>Pj and Ai,j=1 if Pi≤Pj.

PWs are also characterized by an "individual random factor" attribute, which determines part of the variability in their supplies (the other part being determined by the random factor associated with the stockpiling locality). This factor is equal to HI i, HI being an attribute of the PW class (HI is equal for all PWs) and i being randomly determined at each time step for each PW. (i can take the values -1, 0, and 1 with equal probability.) So, as we saw it above, the random quantity supplied to the PWs is given by the formula (1): *qS = Ed (1 + HI i + HZ z)*. Ed refers to the expected value of the demand addressed to the PW. In the sub-models PLACES and EXCHANGE, Ed is equal for all PWs. Ed is then given by the formula:

$$\text{Ed} = \frac{D}{nbPW} \tag{6}$$

With:
D: global demand of all consumers
nbPW: number of PWs

Combining formulas (1) and (6), we obtain the following formula for the random quantity supplied to the PWs in the sub-models PLACES and EXCHANGE:

$$qS = \frac{D}{nbPW}\ (1 + HI\ i + HZ\ z) \tag{7}$$

In the submodel NETWORKS, the expected value of the demand addressed to a PW is proportional to the number of CWs to whom he is connected. So the expected value of the demand addressed to PW p (Edp) is given by the following formula:

$$\text{Edp} = \text{D}\ \frac{nbCWp}{nbCW * nbPWperCW} \tag{8}$$

With:
D: global demand of all consumers
nbCWp: number of CWs to whom PW p is connected
nbCW: number of CWs
nbPWperCW: number of correspondents PWs per CW (nbPWperCW is an attribute of the CW class i.e. nbPWperCW is equal for all CWs).

Combining formulas (1) and (8), we obtain the following formula for the random quantity supplied to the PWs in the sub-model NETWORKS:

$$qS = D \frac{nbCWp}{nbCW * nbPWperCW} (1 + HI\,i + HZ\,z) \quad (9)$$

In all sub-models, the random price supplied to the PWs (pS) can take the values 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, and 250 with equal probability (whatever the PW and whatever the zone).

The CWs, for their part, know the list of the different stockpiling localities (SLs) to which they can go to buy cereals. They also have a network (the list of their PW correspondents) and a demand d. The list of PW correspondents is determined randomly for each simulation. The demand d is given by the following formula:

$$d = \frac{D}{nbCW} (1 + \alpha) - QS \quad (10)$$

With:
D: global demand of all consumers
nbCW: number of CWs
α: CWs' aversion to the risk to be out of stock (α is an attribute of the CW class i.e. α is equal for all CWs)
QS: total quantity in the CW's stock. QS = $\sum_{i=1}^{i=n} Qi$

3.1.3 Information flows

Information flows are represented in the model as "messages" composed of prices and quantities. The information held by the agents (PWs and CWs) is entirely expressed by their stocks (a series of "price-quantity" pairs). *This information is distributed to the extent that each agent knows his own stock but not that of the others*. Moreover, this information is subject to exogenous variations, since the supply of each PW at each time step is random.

The random supplies to PWs represent exogenous information flows. This flows are messages composed of price/quantity pairs (pS ; qS), pS and qS being determined randomly in accordance with the formulas presented in the section 3.1.2.

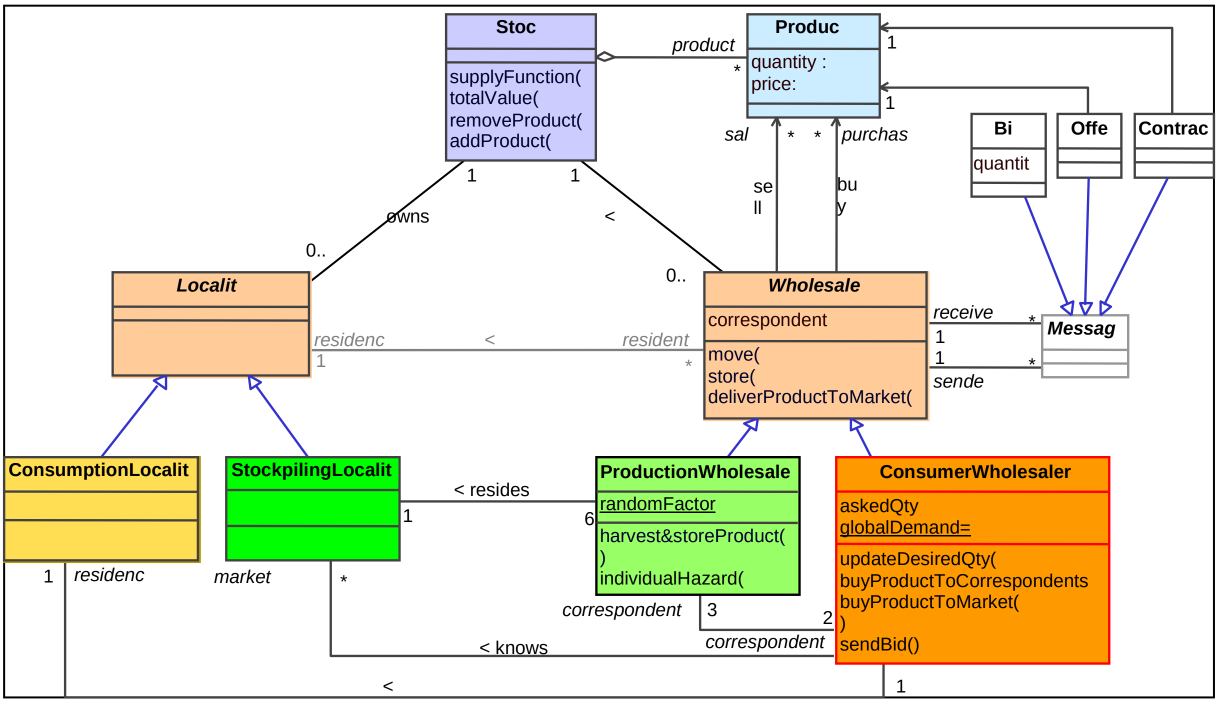
The quality of resource allocation, therefore, depends on information dissemination. This occurs via two different mechanisms:
- *Within marketplaces*, all the information held by each trader (in his "stock" attribute) is made known. The messages sent by the traders are thus complete supply functions summing up all the information they hold. In practice, it is the "spatial entities" of the model that "read" the agents' supply and demand functions, aggregate them, match the overall supply and demand functions obtained in this way, and calculate the price. This information (the price) is then sent to the agents, who use it in their buying and selling behaviors. This reflects the assumption we made of perfect transparency within marketplaces. A marketplace covering all the PWs and CWs in the model thus makes it possible to use all available information, resulting in an optimum allocation of resources. This explains why the EXCHANGE sub-model (used as the benchmark) consists of a single marketplace grouping all the PWs and all

the CWs. This information dissemination procedure is also used in the other two models. In PLACES, this process takes place at the level of each stockpiling locality (SL) and each consumption locality (CL). In NETWORKS, this process takes place only at the consumption locality level. (Transactions between PWs and CWs take place within trade networks.)
- *Within trade networks*, information dissemination is very different. The messages sent by potential buyers and sellers are much briefer. Not all the information held by the agents (in the form of their supply and demand functions) is disseminated, but only a quantity (in the case of the bids sent by the CWs to their PW correspondents) or a price/quantity pair (in the case of the PWs' replies in the form of offers) or, lastly, a binary variable corresponding to the acceptance or rejection of offers formulated by PWs.

In short, the information dissemination mechanisms vary according to the market institutions modelled. For the PLACES sub-model, and the EXCHANGE benchmark sub-model, only information dissemination within marketplaces is used. In the NETWORKS sub-model, two mechanisms are brought into play: trade networks for transactions between PWs and CWs, and marketplaces for transactions between CWs and consumers. As the mechanism used (at the consumption locality level) for transactions between CWs and consumers is the same in NETWORKS and in PLACES, it is on the upstream level of transactions between PWs and CWs that the difference in performance between the two institutions is generated.

The UML diagram displays the different entities of the model and their interrelations (Fig. 3).

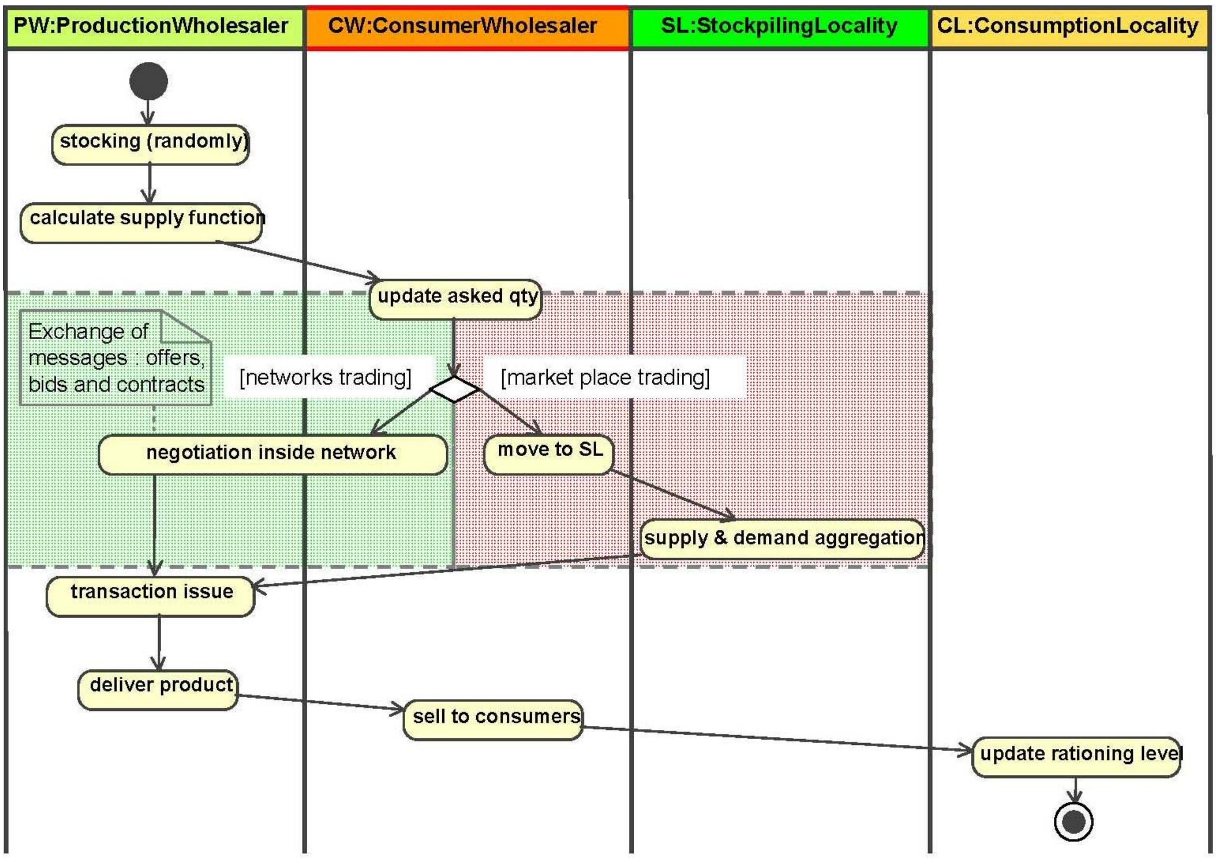
Figure 3. Model class diagram according to the UML mode of representation



3.2 Model dynamics

The same chronology is applied for all scenarios. The following stages occur for each time step. First, the PWs receive random supplies in the form of a price/quantity pair which enable them to update their stock. This stock, expressed as a vector of price/quantity pairs, enables them to calculate their supply function. Second, the CWs calculate their demand (expressed as a simple quantity). The third stage corresponds to the exchange of messages (offers and bids) between PWs and CWs, which correspond to the negotiation and transaction process. It is here that the scenarios diverge depending on the market institution (marketplace trading, network trading or benchmark institution). At the end of the process, the stocks of the PWs and CWs are updated. Lastly, the CWs calculate their supply function from their stock. The supply functions of the different CWs are aggregated at the level of each consumption locality. This collective supply function is then matched against the demand (constant) from the locality. This gives a market price, a rationing level and a sales level for each CW, making it possible to update their stock. These dynamics are shown in Figure 4.

Figure 4. Diagram of model activity over a given time step.



The only difference between the scenarios simulating network trading (NETWORKS) and marketplace trading (PLACES) lies in stage 3, which simulates the negotiations and transactions between PWs and CWs. In the *PLACES sub-model*, each CW, after calculating his demand (stage 2), randomly chooses a stockpiling locality where he goes to obtain his supplies. Then, in each SL, the aggregate demand of the CWs is calculated by adding individual demands. This demand is then matched against the collective supply function of the PWs in the locality, obtained by aggregation of their individual supply functions. This determines a price and a set of transactions, which then makes it possible to update the stocks of the PWs and the CWs. The CWs then return to their consumption locality and sell (stage 4). In the *NETWORKS sub-model*, the stage 3 sequence is very different: *a)* each CW sends a message to his PW correspondents (each located in a different SL) indicating the quantity demanded d ; *b)* the PWs match this quantity against their individual supply functions and determine their offers (composed of a price/quantity pair, where the quantity may be equal to d or lower if the PW does not have sufficient stocks to meet the total demand); *c)* this offer is the content of the message sent back to the CW; *d)* the CW examines the offers received and chooses the one offering the best price. He then sends an acceptance message to the corresponding PW and calculates the difference between the quantity demanded and the quantity supplied by this PW. If the difference is positive (i.e. if the PW's offer does not cover the entire quantity d), the CW sends another message to his other PW correspondents with the new demanded quantity d'. They make other offers (based on this new demanded quantity), which are examined by the CW. The process stops when the CW has satisfied his demand or when all his PW correspondents have an empty stock.

Note that the CWs act in succession. In other words, each "conversation" between a CW and his PW correspondents is completed before another CW begins contacting his correspondents. The consequence of this timing is that each PW only receives a request from one CW at a time. This corresponds fairly well to the behavior of PWs, who try to satisfy the demands of their CW correspondents on a "first come, first served" basis. So the CWs who act first have an advantage over their competitors, as the stocks of the PWs have not yet been depleted by their sales. To represent the fact that it is not always the same CWs who act first, in the model, the order in which the CWs contact the PWs is decided at random for each time step.

3.3. Model "outputs" and performance indicators

As already noted, the performance indicators are linked to the level of rationing in the consumption localities. In the model, the consumer rationing is measured at the level of each consumption locality (CL). The rationing levels by CL are then aggregated by simple addition to obtain an indicator R measuring the overall consumer rationing:

$$R = \sum_{i=1}^{i=n}(Bi - \sum_{j=1}^{j=Ni} Sij) \qquad (11)$$

With
R: Overall level of rationing for all consumers
n: Number of consumption localities
Ni: Number of wholesalers (CWs) in consumption locality i
Bi: Cereal requirement of consumers in locality i over one time step
Sij: Cereal stock of the j^{th} wholesaler in locality i

R measures the rationing generated during a time step. The rationing generated by a simulation of t time steps is the sum of the rationing at each time step. Using formulas (2), (3), (4), and (5), it is then easy to calculate the indicators of performance P, LP and RLP of the different environment/market institution pairs simulated (see section 2.4).

We have presented the structure of the Markets model, which was programmed in smallTalk using visualWorks software. It was implemented on CIRAD's CORMAS platform (Bousquet et al., 1998).

4. THE SIMULATIONS AND THEIR RESULTS

In this section, we present the experimental plan, the expected results (hypotheses tested) and the results obtained. The economic interpretation of these results is covered in the following section.

4.1. Model reliability testing

We checked the reliability of the model in different ways. First, we tested separately each part of the program by comparing the result it generates with the expected result (calculated separately). Second, we tested the model as a whole. To do this, we verified whether certain results already known were also obtained by the simulation. These simulations were performed with the benchmark institution (EXCHANGE), for which theoretical results are available. More precisely, it was known that the following results should be obtained:

a) Rationing should be nil when there is no random factor (HI = HZ = 0), as in this case, overall supply (supply of wholesalers) is the same at each time step. Given the calibration of the model, this overall supply is equal to overall demand (demand from the consumption localities). As supply and demand are centralized, total supply matches total demand, and hence there should be no rationing.
b) Rationing should increase when random factors increase (increase in HI or HZ).
c) Rationing should increase more when the zone-related random factor increases (increase in HZ) than when the PW-related random factor increases (increase in HI). Indeed, in the first case, the random factors concerning the supply of the different PWs are correlated, so that centralization of PW supply is less effective in reducing the variability of overall supply (by applying the law of large numbers).

To test these results, we estimated the equation R [EXCHANGE] = α HI + β HZ + γ and tested the significance of parameters α, β, and γ. We expected that $\gamma = 0$ (result a), $\alpha > 0$ and $\beta > 0$ (result b), and $\beta > \alpha$ (result c). As can be seen in Table 1, the expected results are actually obtained, thereby strengthening our degree of confidence in the model.

Table 1. Model reliability testing

R-squared = 0.8772 Adj R-squared = 0.8764

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	60942	4362	13.97	0.00	52358	69527
HZ	196289	4362	45.00	0.00	187705	204874
Constant	4598	2780	1.65	0.10	-873	10070

4.2. Experimental plan

The model *Markets* contains many variables: nbSL, nbCL, nbPW, nbCW, nbPWperCW, HI, HZ, α, and D. Some of the variables were considered as fixed parameters (equal in all the scenarios simulated). The fixation of the value of these parameters refers to the *calibration* of the model. Other variables play a crucial role in our hypotheses about the performance of marketplace trading and network trading: the number of PWs (nbPW), the weight of the hazard linked to the individual (HI) and the weight of the hazard linked to the zone (HZ). For these, we performed *sensitivity analyses*. So, the values given to nbPW, HI, and HZ defined the different environments simulated. Combining these environments with the institutions, we obtained the *scenarios* simulated. For the *implementation of simulations*, we also fixed others parameters, such as the duration of the simulations and the number of repetitions of the scenarios.

Calibration of the model. For the sake of simplicity, the number of localities must be kept to a minimum. We therefore opted for a configuration with two consumption localities (CL) and three stockpiling localities (SL). This spatial organization roughly corresponds to that prevailing in southern Benin, where two major consumption localities (Cotonou and Porto-Novo) are supplied by three major stockpiling localities (Kétou, Pobè and Azovè). Above all, it was important to introduce at least three SLs to model the fact that, in network trading, CWs can only choose from among a sub-set of the different SLs (those where they have correspondents). For this reason, in NETWORKS sub-model, the number of PW correspondents of each CW (nbPWperCW) was fixed at two. The aversion of CWs to the risk of being out of stock (α) was fixed to 20%, in line with observations of cereal traders' buying strategies in Mali and Benin (Galtier, 2002a). The number of CWs was fixed at 60. This value fits well with empirical data from Mali and Benin. The global demand of consumers (D) was arbitrarily fixed to 60,000. To sum up, the values of the fixed parameters of the model were: nbSL = 3, nbCL =2, nbCW = 60, nbPWperCW = 2, α = 20%, and D= 60,000.

Sensitivy analyses. As we saw above, in all the simulations performed, the environment was defined by three elements: the number of PWs (nbPW), the weight of the hazard linked to the individual (HI) and the weight of the hazard linked to the zone (HZ). As we wanted to test the impact of these variables on the performance of different market institutions, we chose a wide range of modalities for them. For nbPW, we introduced twenty modalities: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54, 57, and 60 (3 and 60 being roughly the minimum and maximum observed in West-African cereal markets). For HI and HZ, we didn't have empirical data (as traders are reluctant to give information on this kind of sensitive data). So, we chose to cover a very wide range of modalities for HI and HZ: 0%, 25%, 50%, 75%, and 100%. But a technical constraint of the model imposes HI + HZ ≤ 1 (see section 2.4), so we chose to take all the combinations of these modalities that satisfy this constraint. This gave us fifteen (HI ; HZ) pairs.

Scenarios. The purpose of this modelling work is to test the performance of different market institutions within different environments. A scenario of the model therefore corresponds to a market institution/environment pair. Three *market institutions* were modelled: marketplace trading ("PLACES" sub–model), network trading ("NETWORKS" sub-model) and the benchmark institution ("EXCHANGE" sub-model). Crossing these three institutions with the 300 environments defined above, this gave us a total of 900 scenarios to be tested (see Table 2).

Table 2. The different scenarios tested

	Variables	Modalities	Number of modalities
ENVIRONMENT			
- Weight of random factors linked to the PW (HI) and linked to the zone (HZ)	(HI ; HZ)	(0 ; 0) (0 ; 0,25) (0 ; 0,5) (0 ; 0,75) (0 ; 1) (0,25 ; 0) (0,25 ; 0,25) (0,25 ; 0,5) (0,25 ; 0,75) (0,5 ; 0) (0,5 ; 0,25) (0,5 ; 0,5) (0,75 ; 0) (0,75 ; 0,25) (1 ; 0)	15
- Number of PWs	nbPW	3 ; 6 ; 9 ; 12 ; 15 ; 18 ; 21 ; 24 ; 27 ; 30 ; 33 ; 36 ; 39 ; 42 ; 45 ; 48 ; 51 ; 54 ; 57 ; 60	20
MARKET INSTITUTIONS	Sub-model	NETWORKS ; PLACES ; EXCHANGE	3

Implementation of simulations. Each of the 900 scenarios was simulated over 100 time steps, approximately corresponding to two farming seasons, taking a model time step to be a week in reality (numerous marketplaces operate on a weekly basis). However, one simulation per scenario is not enough. Indeed, as several random variables were introduced into the model, different simulations performed from the same environment/market institution pair may lead to different market processes and contrasting performances. This problem can only be overcome by performing numerous simulations for the same scenario. So, the performance indicators used are based on the mean rationing brought about by a simulation "package". Testing showed that the mean rationing obtained from 1,000 simulations varied very little. We therefore opted to perform 1,000 simulations for each scenario, making a total of 900,000 simulations.
It is now time to present the simulation results. We will examine in succession the expected results (tested hypotheses) and the results obtained. The following section discusses the economic significance of these results.

4.3. Expected simulation results

In line with the arguments developed by some economists from the Austrian School, we expected that decentralized market institutions such as network trading and marketplace trading may have a good level of performance (see section 2.3). The *levels of performance of network trading and marketplace trading* were defined as the gap between their performance and a perfect allocation of resources. They were calculated taking as a reference not the global demand of consumers (like indicator P) but the amount of satisfied demand generated by a perfect allocation of resources (see section 2.4). The reason for this is that the global demand of consumers is not reachable in the model due to the occurrence of physical imbalance between supply and demand. This led us to define two indicators: the *level of performance of institution X* (the performance of X minus performance of the optimal institution EXCHANGE) and *the relative performance of institution X* (the performance of X on the performance of the optimal institution EXCHANGE). To confront the Austrian School hypotheses, we represent graphically LP [NETWORKS], LP [PLACES], RLP [NETWORKS], and RLP [PLACES] as a function of the more discriminating variables of the environment.

The main results expected from the simulations concerned what determines *the comparative performance of network trading and marketplace trading*. The performance of an institution X in an environment (HI ; HZ ; nbPW) has been defined in section 2.4 as the volume of satisfied demand (i.e. global demand of consumers minus rationing). Our hypotheses about what determines the comparative performance of network trading and marketplace trading have been presented in section 2.3. The first hypothesis (H1) is that *variability of supply to PWs linked to the individual should improve the comparative performance of marketplace trading*. The second hypothesis (H2) is that *variability of supply to PWs linked to the zone should improve the comparative performance of network trading*. The third hypothesis (H3) is that *the number of PWs should improve the comparative performance of marketplace trading*. All these hypotheses can be formulated with the variables that represent the environment in the model: HI, HZ, and nbPW. The hypotheses H1, H2 and H3 can then be tested in an econometrical way.
Equation (12) gives the comparative performance of network trading and marketplace trading depending on HI, HZ, and nbPW:

$$P\ [NETWORKS] – P\ [PLACES] = \alpha\ HI + \beta\ HZ + \gamma\ nbPW + \delta \qquad (12)$$

With:
P [NETWORKS]: performance of sub model NETWORKS in environment (HI ; HZ ; nbPW)
P [PLACES]: performance of sub model PLACES in environment (HI ; HZ ; nbPW)
HI: weight of the hazard linked to the individual
HZ: weight of the hazard linked to the zone
nbPW: number of PWs

Testing hypotheses H1, H2, and H3 is then easy (we chose a significance level of 5 %):
H1 is verified if $\alpha < 0$
H2 is verified if $\beta > 0$
H3 is verified if $\gamma < 0$

If H3 is verified, it could be explained by two different arguments (see section 2.3). The first is that nbPW has a positive impact on marketplace trading performance because it dilutes the effect of HI (H3a). This impact should disappear when HI = 0. (In this case, we expect nbPW to have no significant impact on marketplace trading performance.) The second argument is that nbPW should have a negative impact on network trading performance because it reduces the level of connection between networks (H3b). This impact should occur even when HI = 0. Both hypotheses can then be tested. We have to estimate the following equations:

$$P\ [PLACES] = \alpha 1\ HI + \beta 1\ HZ + \gamma 1\ nbPW + \delta 1 \qquad (13)$$

$$P\ [PLACES] = \beta 2\ HZ + \gamma 2\ nbPW + \delta 2 \qquad \text{with } HI = 0 \qquad (14)$$

$$P\ [NETWORKS] = \alpha 3\ HI + \beta 3\ HZ + \gamma 3\ nbPW + \delta 3 \qquad (15)$$

$$P\ [NETWORKS] = \beta 4\ HZ + \gamma 4\ nbPW + \delta 4 \qquad \text{with } HI = 0 \qquad (16)$$

H3a is verified if $\gamma 1 > 0$ and $\gamma 2 = 0$
H3b is verified if $\gamma 3 < 0$ and $\gamma 4 < 0$

4.4. The results obtained

First, we will look at the *performance levels of network trading and marketplace trading* by comparing the rationing levels generated by NETWORKS and PLACES sub-models with those generated by the EXCHANGE benchmark institution (which permits optimum resource allocation). We will then present the results regarding the *comparative performance of network trading and marketplace trading* by comparing the levels of rationing generated by the NETWORKS and PLACES sub-models for each of the 300 environments simulated. Finally, we will *confront our results with some previous results* about the performance of marketplace trading and network trading.

4.4.1. Analysis of the performance levels of network trading and marketplace trading

Figures 5 and 6 give the relative levels of performance of NETWORKS and PLACES (depending on HZ). Both institutions reach a very high relative level of performance. *The performance of NETWORKS is almost always above 99.5 % of the optimum allocation of* *resources*. The performance of PLACES is very good as well. *In the worst case, it represents more than 98 % of optimum allocation of resource.*

Figure 5. Relative level of performance of network trading as a function of HZ

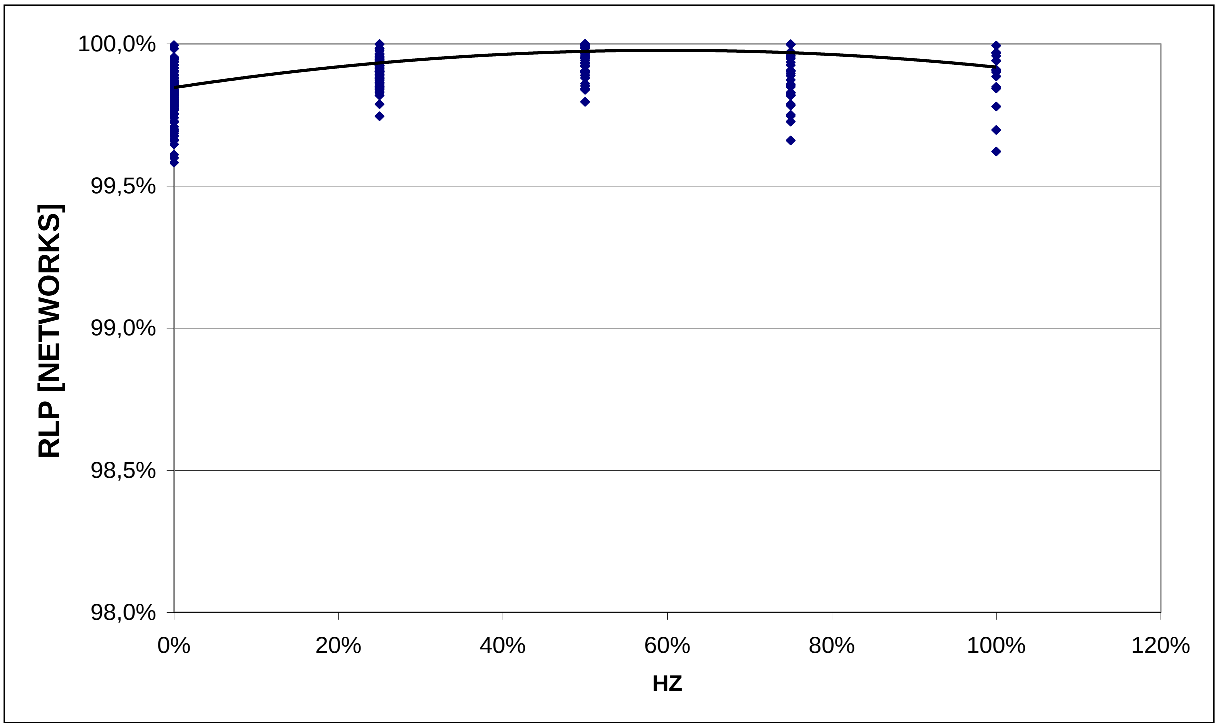
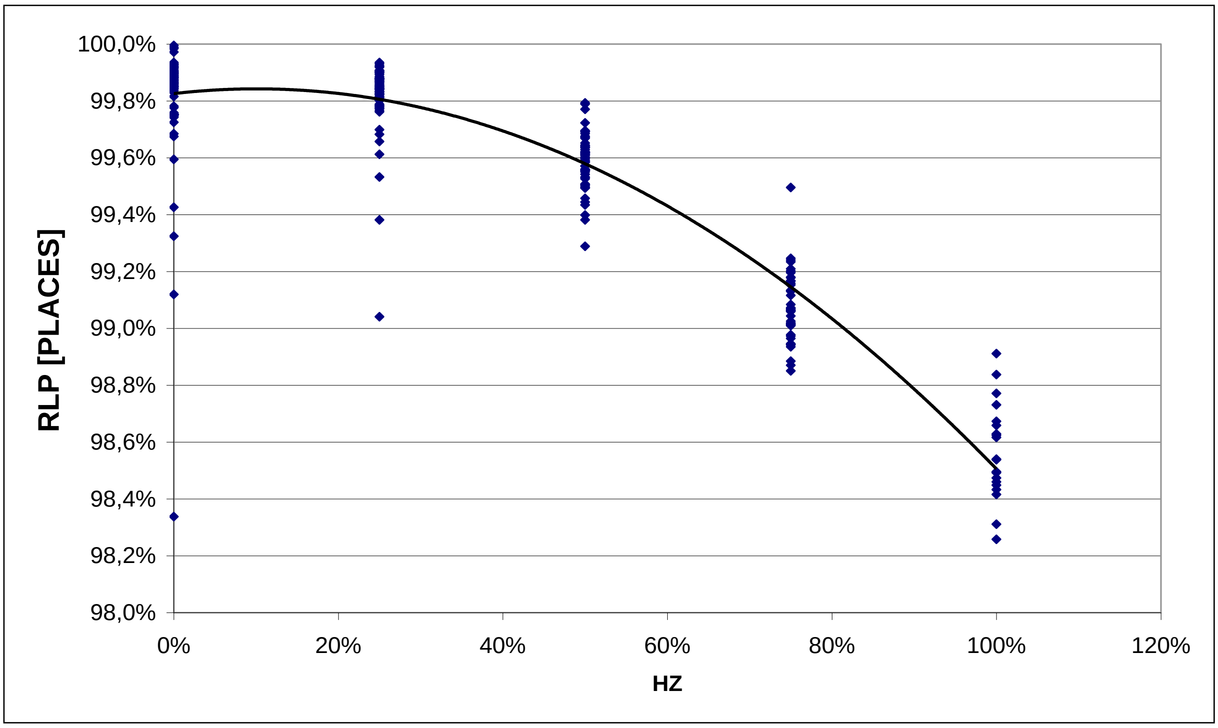


Figure 6. Relative level of performance of marketplace trading as a function of HZ



Let us consider the indicators of the performance levels (see Figures 7 and 8).

Figure 7. Level of performance of network trading

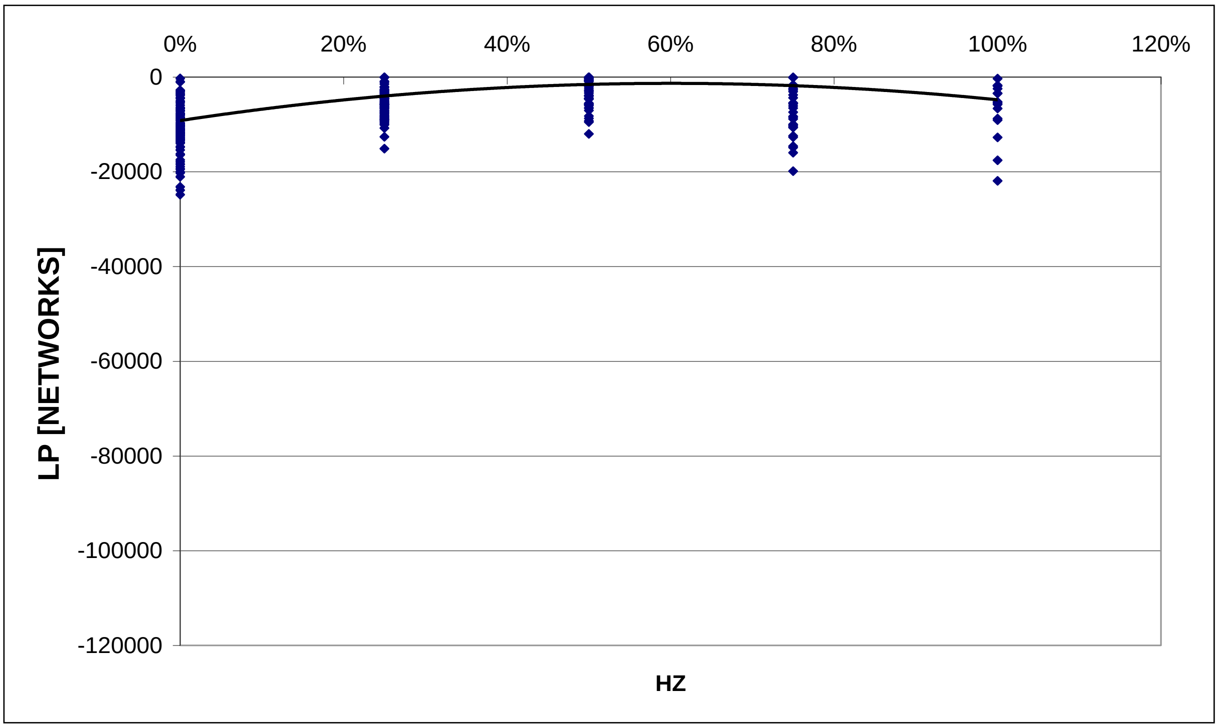
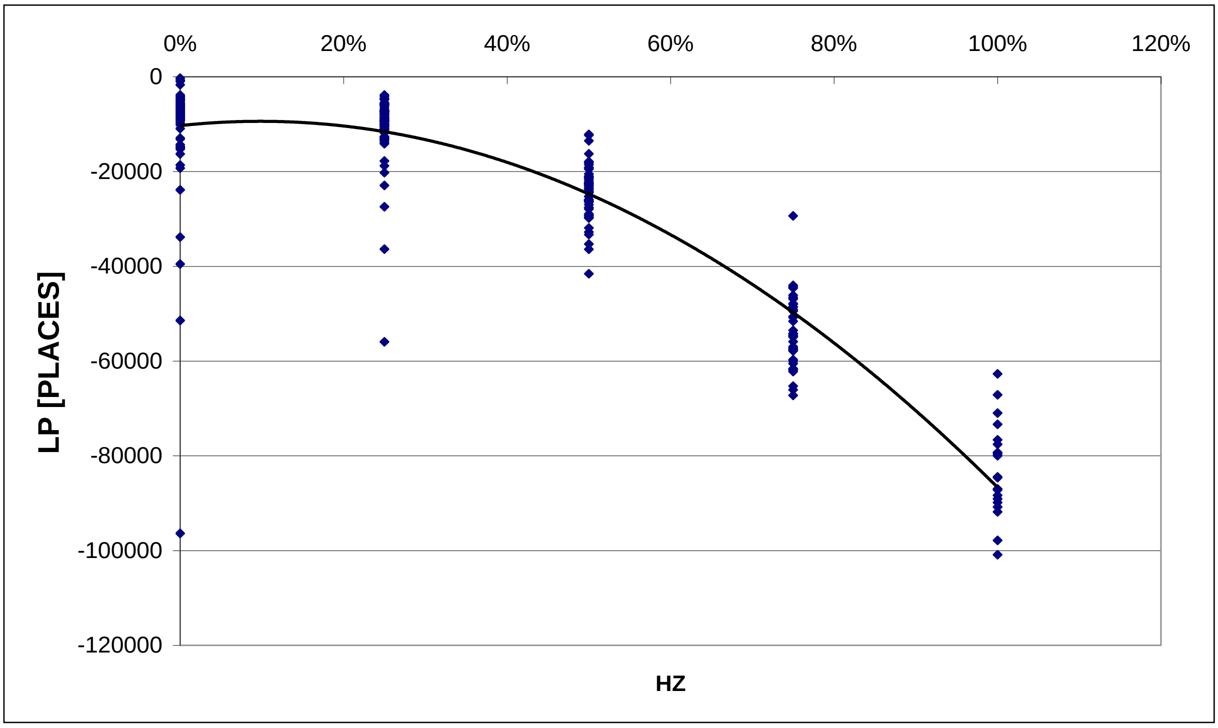


Figure 8. Level of performance of marketplace trading



The level of performance of NETWORKS is almost always above -20,000. That is to say, the difference with the perfect benchmark institution is almost always lower than 20,000 units. Is it a big difference? Remember that we measure the rationing during 100 steps and that the consumers' demand by step was fixed to 60,000. If we consider that a step in the model is a week in the real world, the difference with optimum allocation is around one day of consumption per year. We can consider this a very small difference. What about PLACES? The level of performance of PLACES is about -10,000 (when HZ = 0), but it falls to -30,000 (when HZ = 50%) to reach about -90,000 (when HZ = 100%). A performance level of –90,000 corresponds to one and half week of consumption. So, the difference with optimum allocation represents around five days per year. Is it a significant difference? If the rationing were homogeneously distributed among consumers, this difference would imply a privation of five days per year for each consumer, which normally is not a danger for life (except for vulnerable people such as children or those who are ill). But the distribution of rationing is not homogeneous. Scarcity entails a rise in prices. So the rationing is concentrated on the poorest consumers. A rationing of five-days of consumption may imply in reality a rationing of fifty days per year for 10% of consumers. We can then say that institutions matter: depending on the market institution, the level of food security of the country may be highly different.

In general terms, we can consider that the levels of performance of NETWORKS and PLACES are very high (closed to an optimum allocation of resources). Nevertheless, market institutions matter: for strategic markets (as staple product), the observed differences in performance may have great social consequences.

4.4.2. Analysis of the comparative performance of network trading and marketplace trading

We can visualize the relevance domains of NETWORKS and PLACES (see Table 3).

Table 3. Relevance domains of NETWORKS and PLACES

			nbPW																			
			3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
(HZ ; HI)	0	0	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	0,25	N		N				P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	0,5	N	N							P	P	P	P	P	P	P	P	P	P	P	P
	0	0,75	N	N	N	N	N					P	P	P	P	P	P	P	P	P	P	P
	0	1	N	N	N	N	N	N				P	P	P	P	P	P	P	P	P	P	P
	0,25	0	N	N	N	N	N	N	N	N	N	N										
	0,25	0,25	N	N	N	N	N	N		N			N									
	0,25	0,5	N	N	N	N	N				N					N	N				P	
	0,25	0,75	N	N	N	N	N	N	N	N							P	P		P		
	0,5	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,5	0,25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,5	0,5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,75	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,75	0,25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	1	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

In this table, "N" means that P [NETWORKS] – P [PLACES] > 0, "P" means that P [NETWORKS] – P [PLACES] < 0, and an empty cell means that P [NETWORKS] – P [PLACES] is not statistically different from zero.

It appears that each institution is relevant in some type of environments. For HZ ≥ 50%, NETWORKS is always better. When HZ = 0 or HZ = 25%, either institution can be better depending on the others parameters of the environment (HI and nbPW). For low values of nbPW, NETWORKS is usually better, whereas it is the reverse for high values of nbPW.

What explains the comparative performance of network trading and marketplace trading? The results of the regression of equation (12) can be seen in Table 4. The first result is that HI has a statistically significant positive impact on P [NETWORKS] – P [PLACES]. As a negative impact was expected, this leads to reject hypothesis H1. The second result is that HZ has a significant and positive impact on P [NETWORKS] – P [PLACES], which confirms hypothesis H2. The third result is that nbPW has a significant and negative impact on P [NETWORKS] – P [PLACES], which confirms hypothesis H3. *So, HZ and nbPW have the expected impacts on the comparative performance of the two institutions: HZ plays in favor of network trading and nbPW in favor of marketplace trading. By contrast, HI has a surprising impact on the comparative performance: it provides an advantage to network trading.*

Table 4. The determinants of P [NETWORKS] – P [PLACES] (estimation of equation 12)

R-squared = 0.8223 Adj R-squared = 0.8205

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	4591	2243	2.05	0.04	178	9005
HZ	72050	2243	32.13	0.00	67637	76463
nbPW	-304	35	-8.70	0.00	-373	-236
Constant	2927	1805	1.62	0.11	-626	6480

The results of the regressions of equations (13), (14), (15), and (16) are shown in Tables 5, 6, 7 and 8.

Table 5. The effects of nbPW on P [PLACES] (estimation of equation 13)

R-squared = 0.8870 Adj R-squared = 0.8858

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	-67217	5702	-11.79	0.00	-78437	-55996
HZ	-261522	5702	-45.87	0.00	-272743	-250301
nbPW	651	89	7.31	0.00	476	826
Constant	5974848	4590	1301.75	0.00	5965815	5983881

Table 6. The effects of nbPW on P [PLACES] when HI = 0 (estimation of equation 14)

R-squared = 0.9877 Adj R-squared = 0.9874

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI (dropped)						
HZ	-287393	3257	-88.24	0.00	-293858	-280929
nbPW	-20	67	-0.30	0.77	-152	112
Constant	6000243	2894	2073.43	0.00	5994500	6005987

Table 7. The effects of nbPW on P [NETWORKS] (estimation of equation 15)

R-squared = 0.8961 Adj R-squared = 0.8950

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	-62625	3847	-16.28	0.00	-70197	-55054
HZ	-189472	3847	-49.25	0.00	-197043	-181900
nbPW	346	60	5.77	0.00	228	465
Constant	5977775	3097	1930.19	0.00	5971680	5983870

Table 8. The effects of nbPW on P [NETWORKS] when HI = 0 (estimation of equation 16)

R-squared = 0.9961 Adj R-squared = 0.9960

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI (dropped)						
HZ	-206908	1316	-157.26	0.00	-209519	-204297
nbPW	-126	27	-4.70	0.00	-180	-73
Constant	5994534	1169	5127.72	0.00	5992214	5996854

It appears that nbPW has a positive impact on P [PLACES]. *This impact disappears when HI = 0*. This leads us to accept H3a. The impact of nbPW on the performance of sub-model NETWORKS is more ambiguous. *When HI = 0, nbPW has the expected negative impact on* P [NETWORKS]. *But, in the general case, nbPW has a surprising positive impact on* P [NETWORKS] *(instead of the negative impact that was expected).* This leads us to reject hypothesis H3b.

4.4.3. Comparison with previous results on the performance of marketplace trading and network trading

Our results are consistent with a very robust result of the literature which states that only *regular networks* (in which each agent is in contact with more or less the same number of agents) *can generate an efficient allocation*. Kranton and Minehart (2001) modelled a market network with an allocation mechanism composed of a set of simultaneous ascending-bid auctions between each seller and the buyers linked to him. Corominas-Bosch (2004) analyzed bargaining between buyers and sellers who are connected by an exogenously given network. Ozsoylev (2005) assessed the impact of informal communication networks on information dissemination and resource allocation within assets markets. All found that regular networks can be efficient and that regularity is a necessary condition for efficiency. As all the networks modelled in NETWORKS submodel are regular (all CWs are connected to the same number of PWs and vice-versa), our result that network trading can generate an almost optimum allocation is consistent with the previous literature on this subject. Moreover, the fact that network trading proves to be often more efficient than marketplace trading also confirms that regularity favors efficiency. Indeed, marketplace trading generate irregular networks: as CWs choose randomly the marketplace to which they go, the number of CWs is different in each marketplace and, as a consequence, each PW is connected to a different number of CWs.

Another strong result confirmed here is that *the degree of connection inside the network has usually a positive impact on efficiency*. More specifically, Jackson (2003) showed that if networks are such that each individual has at least two links, then there is no problem of compatibility between efficiency and (pairwise) stability. Our results are consistent with Jackson's because the trade networks represented in the model are very stable (according to empirical evidence in Sahel), prove to be efficient (according to simulation results), and satisfy the condition that each agent is at least connected to two other agents. Our results are also consistent with previous results about risk-sharing networks. Indeed, Bramoullé and Kranton (2007) showed that networks which connect (indirectly) all individuals can lead to the optimum (full insurance). As in almost all the simulations performed, all agents are (indirectly) connected, the very good performance of network trading confirms Bramoullé and Kranton's result. By contrast, the relatively bad performance of marketplace trading may be explained by the disconnection of the different marketplaces (each PW and each CW acts only in one marketplace at a time). Indeed, efficient allocation can be reached by a set multilateral bargaining if there are overlaps between them (Kranton and Minehart 2001).

Another interesting result is provided by the theory of trading groups, as presented by Ioannides (1990). As it is specific to multilateral trade, it can only be compared with our results on the performance of marketplace trading. For Ioannides, the market process inside each trading group may be regulated by a Walrasian mechanism (as in our model for marketplace trading) or by a multi-person Nash bargaining mechanism. He found that, in both cases, the expected utility of trade grows with the size of the group. This is consistent with our result that the performance of marketplace trading grows with the number of PWs per marketplace.

Corominas-Bosch (2004) gave an interesting result specific to the case of bilateral trade that can be compared with our results on network trading. More precisely, she gave a sufficient condition for (regular) networks to be efficient. This condition states that, when the number of sellers is different from the number of buyers, if the long side starts to propose, the network always leads to an efficient allocation (otherwise, the uniqueness of the efficient allocation is not guaranteed). When the number of sellers equals the number of buyers, if the discount rate is small enough, the network is always efficient (otherwise, the uniqueness of the efficient allocation is not guaranteed). In Markets, CWs always start to propose, and in most of the scenarios we have nbCW > nbPW. So, the long side starts to propose. According to Corominas-Bosch 2004, this should imply that the network should always be efficient. In the others scenarios, we have nbPW = nbCW. As there is no discount rate in the model, according to Corominas-Bosch 2004, we should also expect always-efficient networks. Nevertheless, in our simulations, network trading is only closed to efficiency: although some simulations give a zero rationing, most of them generate a low but positive level of rationing. Maybe the main explanation is linked to the timing of the two models. Indeed, in Corominas-Bosch's model, all bargaining behaviors are simultaneous, whereas in our model they are sequential.

5. DISCUSSION

What have we learned about the performance of network trading and marketplace trading in terms of information dissemination and resource allocation?

The first lesson deals with the levels of performance of network trading and marketplace trading (compared with a perfect benchmark institution). It appears that *decentralized market institutions (such as network trading and marketplace trading) manage to generate an allocation of resources that is almost as good as Walrasian market, although they disseminate far fewer bits of information.* This confirms Kirzner's conjecture. It is thus possible to save the travel or communication costs required to assemble all the agents in the same place (either real or virtual). This explains why most real market institutions more closely resemble marketplace trading or network trading than a single Walrasian type market.

The second lesson deals with the comparative performance of network trading and marketplace trading. *In some cases, network trading proves better than marketplace trading in terms of information dissemination and resource allocation*. This challenges the very widespread preconception whereby marketplace trading *always* leads to more transparency than network trading. This result is very important because the idea that marketplace trading is always better has led to public policies: many developing countries have set up wholesale markets in order to improve market transparency. So, the result that network trading may lead to more transparency and to a better allocation of resources should logically induce a total rethink of public policies in this area[5].

The third lesson deals with the type of environment in which each institution is better. *Simulations show that the variability of the supply (*represented in the model by high values of HI and HZ) *gives the advantage to network trading, whereas the atomicity of the supply* (represented by nbPW) *gives the advantage to marketplace trading.* However, HI, HZ, and nbPW have not the same level of importance. The more discriminant is HZ. When HZ ≥ 50%, network trading is always better whatever the value of nbPW and HI (see Table 3). When HZ ≤ 25%, the more discriminant element of the environment is nbPW. Indeed, for small values of nbPW, network trading almost always dominates (whatever the value of HI), whereas it is the reverse for high values of nbPW. To sum up, we can say that *network trading is relevant for environments with a high level of correlated hazard on supply to PWs* or *with a small number of PWs. By contrast, marketplace trading is adapted to environments with a low level of correlated hazard on supply to PWs* and *with a high number of PWs*.

Does this result fit with empirical facts from cereals markets of West Africa? As we have already mentioned it, in this region, the wholesale trade is structured by network trading or by marketplace trading, depending on the country. While network trading prevails in Mali (and in the other Sahel countries), marketplace trading is dominant in Benin and in many other coastal countries. We have some empirical evidences that the correlated hazard on supply to

[5] All the more so as the modelling involves various simplifications that underestimate the performance of network trading and that overestimate the performance of marketplace trading. Indeed, in order to keep the model simple, transaction costs have not been integrated into the model. These costs of search (communication, travel), negotiation, and enforcement are usually lower in the case of network trading because of the repetition of transactions between the same wholesalers. Moreover, real network trading institutions sometimes involve some mechanisms of flexibility (see section 2.2) that have not been included in the analysis. Last but not least, we assumed a perfect transparency at the level of marketplaces (see section 2.4), what is not always the case in the real world (see section 2.2).

PWs (represented by HZ in the model) is high in Mali and relatively low in Benin (Galtier 2002a). Indeed, this correlated hazard stems from shocks affecting simultaneously the sales of many producers of a given zone. As cereals are used by farmers both to feed their family (self-consumption) and as a source of cash income, cereal sales are often limited to what is strictly necessary to cover immediate cash requirements for the family (so as not to deplete the stores). Cereal sales depend therefore on shocks on producers' cereals stocks, incomes and cash needs. We have some evidences that these kind of collective shocks affect much more Mali (and other Sahelian countries) than Benin (and other coastal countries). Indeed, in the Sahel zone, natural shocks are much stronger (lack of rainfall, locust attacks) and producers have a less diversified income and less access to credit. So, the correlated hazard on supply to PWs is high in Mali and relatively low in Benin. As, in Mali, wholesale trade is structured by network trading, *this is consistent with the result of the model that network trading should prevail when HZ is high*[6]. Moreover, the number of PWs is low in Mali (only 3 to 15 PWs per stockpiling locality), whereas it is relatively high in Benin (around 60 small-scale PWs, depending on the stockpiling localities) (Galtier 2002a). *This fits well with the result of the model that marketplace trading should prevail when HZ is low* and *nbPW is high (as is the case in Benin).*

We also found two paradoxical results. The first one is that HI (which was expected to be managed better by marketplace trading) affects more marketplace trading than network trading. The second paradox is linked to the effect of nbPW on the performance of network trading. We expected nbPW to reduce the degree of connection between networks and, by doing so, to have a negative impact on the performance. We obtain this negative impact, but only when HI = 0. When HI > 0, nbPW benefits to network trading. How could we explain these paradoxes? HI represents the variability of supplies to PWs' which is not correlated between PWs. The ability of an institution to manage HI depends on the magnitude of arbitrage between PWs. In marketplace trading, each CW can arbitrate between many PWs ($\frac{nbPW}{3}$ in the simulations performed), whereas, in network trading, each CW can only arbitrate between his correspondents PWs (two PWs in the simulations performed). So, it seems that marketplace trading should manage better HI than network trading.

The only way to explain the first paradox is to assume some kind of broader arbitrage between PWs in the network trading institution. What is striking is that this explanation of the first paradox allows us to understand also the second one. Indeed, if there is a form of broader arbitrage between PWs within network trading institution, nbPW may induce a dilution of the effect of HI (similar to the dilution effect that occur within marketplace trading institution). In this case, nbPW has two effects on network trading performance: a negative due to the reduction of the degree of connection between networks and a positive one due to the dilution of the effect of HI. The first one occurs even when HI = 0, whereas the second one occurs only when HI > 0. When HI = 0, only the negative effect is playing: nbPW has the expected negative impact on network trading performance. When HI > 0, both effects are playing and,

[6] Another empirical confirmation of the link between HZ and network trading can be found in the way the international trade of agricultural commodities is organized. This trade put in relation many production zones affected by natural hazards (climatic shocks, pests and diseases). Inside the zones, these hazards are correlated (they affect many farmers at the same time). On the contrary, at the international level, as the production zones are far from each other, the shocks affecting them are not correlated. In such a situation, our model predicts that network trading is better. As a matter of fact, the international trade of the main agricultural commodities such as coffee or cocoa is based on network trading: importers buy always to the same exporters, arbitrating between different countries but very few between different exporters of the same country. (the existing exchanges such as NYBOT or LIFFE are only used to hedge price risk, not to trade.)

as the positive one proves to be stronger, nbPW has a positive impact on the performance. So, *both paradoxes can be explained by the conjecture that there is some kind of broader arbitrage between PWs in the network trading institution*.

What can be this broader arbitrage between PWs that operates within network trading institution? As, in network trading, CWs only arbitrate between a small number of PWs (their correspondents), it can only be an *indirect* arbitrage between PWs. In network trading, there are only two possible types of indirect arbitrage. In the first one, the CWs arbitrate not only between their correspondents PWs, but also (indirectly) between other PWs. How is it possible? In network trading, CWs are connected to each others by their common correspondents PWs. In this way, they are indirectly connected with the correspondents PWs of the CWs with whom they have at least a common PW. This might allow a form of indirect arbitrage between PWs. Indeed, as CWs act sequentially, the arbitrages performed by CW1 (between PW1 and PW2) and by CW2 (between PW2 and PW3) generate a form of indirect arbitrage between PW1 and PW3 (through the stock of PW2). As this form of arbitrage is performed by the CWs, we will call it "*CWs' indirect arbitrage*". The second type of indirect arbitrage is performed by the consumers. Indeed, in consumption localities, consumers arbitrate between CWs what represent a form of indirect arbitrage between PWs. We will call this type of arbitrage "*consumers' indirect arbitrage*".

We tested our conjecture that a kind of broader arbitrage between PWs exists in the network trading institution and is responsible for the observed paradoxes. Indeed, we performed a new set of 900,000 simulations with the same 900 scenarios (see Table 1), but measuring the rationing at the level of each CW (and not at the level of each consumption locality as in the former simulations). In other words, we eliminated the arbitrage of consumers between CWs which implies that there is no "*consumers' indirect arbitrage*" between PWs. The results are shown in Tables 9, 10, 11, 12, 13, and 14.

Table 9. Relevance domains of NETWORKS and PLACES for simulations without consumers' indirect arbitrage

			nbPW																			
			3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60
(HZ ; HI)	0	0	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	0,25	N	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	0,5	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	0,75	N	N	N	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0	1	N	N	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0,25	0	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0,25	0,25	N	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0,25	0,5	N	N	N		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0,25	0,75	N	N	N			P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	0,5	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,5	0,25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,5	0,5	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N					
	0,75	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	0,75	0,25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	1	0	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 10. The determinants of P [NETWORKS] – P [PLACES] (estimation of equation 12) for simulations without consumers' indirect arbitrage

R-squared = 0.8965 Adj R-squared = 0.8955

Variables	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
HI	1179	4084,75	0,29	0,773	-6860	9218
HZ	165081	4084,75	40,41	0,000	157043	173120
nbpW	-1280	63,76	-20,07	0,000	-1405	-1154
Constant	-17068	3288,23	-5,19	0,000	-23539	-10597

Table 11. The effects of nbPW on P [PLACES] (estimation of equation 13) for simulations without consumers' indirect arbitrage

R-squared = 0.8892 Adj R-squared = 0.8881

Variables	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
HI	-74311	6254,53	-11,88	0,000	-86620	-62002
HZ	-289962	6254,53	-46,36	0,000	-302271	-277653
nbpW	738	97,63	7,55	0,000	545	930
Constant	5947625	5034,90	1181,28	0,000	5937716	5957534

Table 12. The effects of nbPW on P [PLACES] when HI = 0 (estimation of equation 14) for simulations without consumers' indirect arbitrage

R-squared = 0.9891 Adj R-squared = 0.9888

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	(dropped)					
HZ	-313871	3350,29	-93,68	0,000	-320520	-307221
nbpW	5	68,47	0,07	0,947	-131	140
Constant	5973450	2976,81	2006,66	0,000	5967542	5979358

Table 13. The effects of nbPW on P [NETWORKS] (estimation of equation 15) for simulations without consumers' indirect arbitrage

R-squared = 0.8145 Adj R-squared = 0.8126

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	-73131	3611,73	-20,25	0,000	-80239	-66023
HZ	-124881	3611,73	-34,58	0,000	-131989	-117773
nbpW	-542	56,38	-9,62	0,000	-653	-431
Constant	5930557	2907,45	2039,78	0,000	5924835	5936279

Table 14. The effects of nbPW on P [NETWORKS] when HI = 0 (estimation of equation 16) for simulations without consumers' indirect arbitrage

R-squared = 0.9558 Adj R-squared = 0.9549

Variables	Coef.	Std. Error	t	P > | t |	[95% Conf. Interval]	
HI	(dropped)					
HZ	-142042	3165,56	-44,87	0,000	-148325	-135759
nbpW	-597	64,70	-9,23	0,000	-725	-469
Constant	5931785	2812,67	2108,95	0,000	5926202	5937367

First, as expected, the hypotheses H2, H3, and H3a (which have been confirmed by the former simulations) are also confirmed by the simulations without "consumers' indirect arbitrage" (see Tables 10, 11, and 12). Second, hypothesis H3b is now confirmed (nbPW has a negative impact on network trading performance), which proves that "consumers indirect arbitrage" plays a decisive role in the explanation of the second paradox (see Tables 13 and 14). Third, the first paradox remains but is reduced. Indeed, in line with hypothesis H1, we were expecting HI to give the advantage to marketplace trading. The first set of simulations gives the opposite result, whereas simulations without "*consumers' indirect arbitrage*" reveal that the impact of HI in the comparative performance of network trading and marketplace trading is not statistically significant (see Tables 4 and 10). This means that the first paradox is only partially explained by "consumers' indirect arbitrage". This confirms that "CWs' indirect arbitrage" also plays a role.

What is the economic interpretation of this? The significant impact of "CWs' indirect arbitrage" means that the connection between CWs' supply networks matters. The more connected the networks, the better the information dissemination and the resource allocation. The significant impact of "consumers' indirect arbitrage" means that, in some environments, the superiority of network trading on marketplace trading stems from the downstream arbitrages of consumers between CWs. (The comparison of Tables 3 and 9 shows that the relevance domain of network trading is more restricted without "consumers' indirect arbitrage.") How realistic is the hypothesis that consumers do not arbitrate? In West Africa, some consumers have fidelity relations with wholesalers or retailers because they offer them delayed payment. So, the real situation is in-between the perfect arbitrage (our first set of simulations) and the complete lack of arbitrage (our second set of simulations). The two mechanisms of indirect arbitrage explain the surprising performance of network trading which proves to be, in many situations, better than marketplace trading.

6. CONCLUSION

We built a multi-agent model (called Markets) and performed simulations in order to study the information dissemination and allocation process inside two types of market institutions: network trading and marketplace trading. The results obtained by computer simulations have been validated with empirical data from cereal markets in West-Africa.

Computer modelling of market processes with a multi-agent system proves to be an effective means to explain how effective resource allocation can result from the decentralized interactions of numerous individuals among whom the information is distributed. This tool is particularly useful to model market networks more complex (and realistic) than those usually *studied in the literature*. Other tools, such as game theory or market experiments, can also be used for the same purpose (Smith, 1982; Roth, 2001; Balzer et al, 2001). Nevertheless, computer simulations are more effective than game theory for analyzing decentralized markets where transactions take place « out of equilibrium ». They make it possible to involve far more agents than experiments and also to simulate trading processes over a much longer time period. Nevertheless, all these tools are complementary.

We found some interesting results about the role of market networks. First, *the topology of the market network matters:* it proves to have a significant impact on market transparency and performance. So, it is necessary to analyze the network of real markets that are often much more complex than the centralized networks generally studied in the literature. Second, *decentralized and incomplete communication networks such as those of network trading and marketplace trading can lead to a good resource allocation, although they disseminate far fewer bits of information than the Walrasian market.* Third, *network trading may be better than marketplace trading for market transparency and resource allocation* (contrary to a very common preconception). Last but not least, we showed some new results about the network trading institution. The more interesting one is that *network trading does not lead to a segmentation of the market*: the connection between networks (even low) and the downstream arbitrage of the consumers are sufficient to generate a good dissemination of information and a good allocation of resources.

These results can have great implications for market design and public policy. Indeed, as many current policies favor marketplace trading, the result that marketplace trading is *not* always better than network trading for market transparency and resource allocation should be of great interest for market design. The model can also be used in the design of market information systems (MIS) that collect and disseminate price information by radio or SMS in order to make the market more transparent (Dembélé and Staatz, 1989; Galtier and Egg, 2003).

Let us now consider some of the *avenues for further research opened up by this work*:

Introduce heterogeneity (especially irregular networks). In the current version of the model, all the agents of a category (PWs, CWs) are identical. The next step for us is to introduce heterogeneous agents. There are several ways to do this: agents may differ in number of connections, behavioral rules, endowments, or risk aversion. Introducing agents with different number of connections is of special interest. Indeed, there is a strong hypothesis in the literature that only regular networks can be efficient (Kranton and Minehart, 2001; Corominas-Bosch, 2004; Ozsoylev, 2005). It can be very interesting to test this hypothesis and also to characterize more precisely the relation between regularity and efficiency (which is strongly linked to indirect arbitrage). Another interesting subject is related to agents' behavioral rules. For instance, in marketplace trading, we can introduce two types of agents, one with the strategy to choose randomly the marketplace (as in the current version of the model) and one with the strategy to go to the marketplace which had the lowest price in t – 1. We can also introduce a learning process in order to render endogenous the strategy of each agent. The introduction of agents with different levels of endowment can allow us to assess the performance not only at the level of the whole market but also at less aggregated levels (for instance, different classes of consumers).

Analyze the emergence of institutions. In this article, we used computer simulations to assess the efficiency of a market with given institutions. Introducing the transaction costs endured by the agents, it is possible *to explore the processes involved in the emergence of such institutions* (Kirman and Vriend, 2000). It is of special interest to cross both types of analysis in order to check if efficient networks can emerge from the decentralized behaviors of rational agents incurring costs to build links (Kranton and Minehart, 2001; Jackson, 2003; Bramoullé and Kranton, 2007).

Introduce the problem of moral hazard and analyze its consequences on market networks' efficiency. Indeed, apart from the dispersal among economic agents of information relative to endowments, costs and preferences, limited information on agents' ability and honesty may lead to problems in performing transactions (Williamson, 1985; Hoff et al., 1993). This may have an impact on information dissemination processes within markets. For example, in Benin, consumption zone wholesalers who have to travel widely in the production zones of the country, entrust maize sales to brokers (paid on a commission basis). However, this brings in a problem of moral hazard, since these brokers, whose behavior cannot be observed, may be tempted to distort the sales proposals made by wholesalers, thereby introducing a source of "noise" in communication within the market (Galtier, 2002b). A solution can be the dissemination of information on unreliable agents (Milgrom et al., 1990; Greif 1993). But, if the same network plays both the role of a transaction network and of an information network on unreliable agents, this can also have a strong impact on network efficiency (Bloch et al. 2008).

References

Amselle J-L (1977) Les commerçants de la savane: histoire et organisation sociale des Kooroko (Mali). Anthropos, Paris

Aoki M (1986) Horizontal vs. Vertical Information Structure of the Firm. American Economic Review 76: 971-83.

Balzer W, Brendel K, Hofmann S (2001) Bad Arguments in the Comparison of Game Theory and Simulation in Social Science. Journal of Artificial Societies and Social Simulation 4(2), Available on line: http://www.soc.surrey.ac.uk/JASSS/4/2/1.html

Birner J (1999) Making markets. In: Dow S, Earl PE (eds) Economic organization and economic knowledge, pp 36–56. Edward Elgar, Cheltenham

Bloch F, Genicot G, Ray D (2008) Informal insurance in social networks. Journal of Economic Theory, forthcoming.

Bousquet F, Bakam I, Proton H, Lepage C (1998) Cormas: Common-Pool Resources and Multi-Agent Systems. Lecture Notes in Artificial Intelligence 1416: 826-837.

Bramoullé Y, Kranton R (2007) Risk-sharing networks. Journal of Economic Behavior and Organization 64: 275-294.

Corominas-Bosch M (2004) Bargaining in a network of buyers and sellers. Journal of Economic Theory 115: 35-77.

Brenner T (1997) Learning at the Market Place. Second International Conference on Computing in Economics and Finance.Geneva, Switzerland, 26-28 June 1996

Dembélé N, Staatz J (1989) Transparence des marchés céréaliers et rôle de l'état: la mise en place d'un système d'information des marchés au Mali. European Association of Agricultural Economists Seminar, Montpellier, France.

Durlauf S (1994) Bilateral Interactions and Aggregate Fluctuations. In: Lakshmikantham V (ed) Proceedings of the First World Congress of Nonlinear Analysts Volume III. Walter DeGruyter, 1996

Egg J, Galtier F, Grégoire E (1996) Systèmes d'information formels et informels: la régulation

des marchés céréaliers au Sahel. Cahiers des Sciences Humaines 32(4): 845-868
Evstigneev I, Taksar M (2008) Dynamic interaction models of economic equilibrium. Journal of Economic Dynamics and Control, forthcoming..
Fafchamps M, Minten B (2001) Social Capital and Agricultural Trade. American Journal of Agricultural Economics 83(3): 630-685
Feldman A (1973) Bilateral trading processes, pairwise optimality and Pareto optimality. Review of Economic Studies 40: 463-479
Föllmer H. (1974) Random economics with many interacting agents. Journal of Mathematical Economics 1: 51-62
Galtier F (2002a) Information, institutions et efficacité des marchés. Trois filières céréalières d'Afrique de l'Ouest analysées comme des systèmes de communication. PhD,.ENSA.M, Montpellier, France
Galtier F (2002b) Eclatement et incomplétude de la théorie des marchés. Economies et Sociétés 36(9-10): 1655-71
Galtier F, Egg J (2003) Le "paradoxe" des systèmes d'information de marché (SIM): une clef de lecture issue de l'économie institutionnelle et de la théorie de la communication. Economies et Sociétés 37(7-8): 1227-1260
Granovetter M (1985) Economic action and social structure: the problem of embeddedness. American Journal of Sociology 91: 481-510
Granovetter M (1994) Les institutions économiques comme constructions sociales: un cadre d'analyse. In: Orléan A (ed) Analyse économique des conventions. Presses Universitaires de France, Paris
Grégoire E (1986) Les Alahzaïs de Maradi: histoire d'un groupe de riches commerçants sahéliens. Editions de l'ORSTOM, Paris
Greif A (1989) Reputation and Economic Institutions in Medieval Trade: Evidences from the Geniza Documents. Journal of Economic History
Greif A (1993) Contract Enforceability and Economic Institutions in Early Trade: The Maghribi Traders Coalition. American Economic Review 83(3): 525-548
Grossman S (1989) The Informational Role of Prices. MIT Press, Cambridge
Grossman S, Stiglitz J (1976) Information and Competitive Price Systems. American Economic Review 66: 246-253
Grossman S, Stiglitz J (1980) On the Impossibility of Informationally Efficient Markets. American Economic Review 70(3): 393-408
Hamadou S (1997) Libéralisation du commerce des produits vivriers au Niger et mode d'organisation des commerçants privés : les réseaux marchands dans le fonctionnement du système de commercialisation des céréales. PhD, ENSAM, Montpellier, France
Hardle W and Kirman A (1995) Nonclassical demand. A model-free examination of price-quantity relations in the Marseille fish market. Journal of Econometrics 67: 227-257
Hayek F (1937) Economics and knowledge. Economica (4): 33-54
Hayek F (1945) The Use of Knowledge in Society. American Economic Review 35(4): 519-530
Hayek F (1948) The Meaning of Competition. In: Hayek F (ed) Individualism and Economic Order. The University of Chicago Press, Chicago
Hoff K, Braverman A, Stiglitz J (1993) The economics of rural organization. Oxford University Press for the World Bank, New York
Hurwicz L (1969) Centralization and Decentralization in economic systems. On the Concept and Possibility of Informational Decentralization. American Economic Review 59: 513-524
Ioannides Y (1975) Market Allocation through Search: Equilibrium Adjustment and Price Dispersion. Journal of Economic Theory 11(2): 247-262

Ioannides Y (1990) Trading Uncertainty and Market Form. International Economic Review 31(3): 619-638
Ioannides Y (1997) The Evolution of Trading Structures. In: Arthur B, Durlauf S, and Lane D (eds) The Economy as an Evolving Complex System II. SFI Studies in the Sciences of Complexity, Addison-Wesley, Reading, MA
Jackson M (2003) The stability and efficiency of economic and social networks. In: Sertel M Koray S (eds) Advances in economic design. Springer.
Jovanovic B (1987) Micro Shocks and Aggregate Risk. Quarterly Journal of Economics 102(2): 395-410
Kirman A (1987) Graph theory. In: Eatwell J, Milgate M, and Newman P (eds) The New Palgrave: a Dictionary of Economics Vol. 1: 190-195. Mc Millan, London
Kirman A (1997) The Economy as an Evolving Network. Journal of Evolutionary Economics 7: 339-353
Kirman A, Schulz R, Hardle W, and Werwatz A (2005) Transactions that did not happen and their influence on prices. Journal of Economic Behavior & Organization 56(4): 567-591
Kirman A, Vriend N (2000). Evolving Market Structure: An ACE Model of Price Dispersion and Loyalty. Journal of Economic Dynamics and Control 25(3-4): 459-502
Kirzner I (1992) The Meaning of Market Process - Essays in the Development of Modern Austrian Economics. Routledge, London
Kirzner I (1997) Entrepreneurial Discovery and the Competitive Market Process: an Austrian Approach. Journal of Economic Litterature 35: 60-85
Kranton R, Minehart F (2001) A Theory of Buyer-Seller Networks. American Economic Review 91(3): 485-508.
Kuiper E, Lutz C, Van Tilburg A (2003) Vertical Price Leadership on Local Maize Markets in Benin. Journal of Development Economics 71: 417–33
Lambert A, Egg J (1994) Commerce, réseaux et marchés: l'approvisionnement en riz dans les pays de l'espace sénégambien. Cahiers des Sciences Humaines 30: 229-254
Milgrom P, North D, Weinsgast B (1990) The role of institutions in the revival of trade : the Law merchant, private judges and the champagne fairs. Economics and Politics 2(19): 1-23.
Ozsoylev H (2005) Asset Pricing Implications of Social Networks. AFA 2006 Boston Meetings Paper. Available at SSRN: http://ssrn.com/abstract=686485
Potts J (2001) Knowledge and markets. Journal of Evolutionary Economics 11(4): 413-431
Radner R (1968) Competitive Equilibrium under Uncertainty. Econometrica 36: 31-58
Radner R (1972) Existence of Equilibrium Plans, Prices and Price Expectations in a Sequence of Markets. Econometrica 40: 289-303
Roth A (2001) The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics. Econometrica 70(4): 1341-1378
Roth A and Peranson E (1999) The Redesign of the Matching Market for American Physicians: Some Engineering Aspects of Economic Design. American Economic Review 89: 748-80
Roth A, Xing X (1997) Turnaround Time and Bottlenecks in Market Clearing: Decentralized Matching in the Market for Clinical Psychologists. Journal of Political Economy 105: 284-329
Schnabl H (1996) A close eye on the invisible hand. Journal of Evolutionary Economics 6(3): 261-280
Smith V (1982) Markets as economizers of information: experimental examination of the "Hayek hypothesis". Economic Inquiry 20: 165-179
Smith V, Williams A, Bratton K, and Vannoni M (1982) Competitive market institutions: double auction versus bid-offer auctions. American Economic Review 72: 58-77

Thomsen E (1992) Prices and Knowledge - A Market-Process Perspective. Routledge, London
Weisbuch G, Kirman A, and Herreiner D (2000) Market Organisation and Trading Relationships. Economic Journal 110(463): 411-436
Williamson O (1985) The Economic Institutions of Capitalism. The Free Press, Mac Millan, New York