Effects of exploration and experimentation capacity on industry competitiveness
Results from an agent-based simulation model

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Abstract
In the behavioural and evolutionary theoretical perspectives it is usually supposed that agents' performance depends significantly on their searching and learning strategies. Moreover, it is widely acknowledged that opportunistic behaviors do take place in the form of cheating attitude in many types of markets. All these issues are here simulated in an agent-based model of industry, whose firms, in order to achieve competitive advantages, look for the best product quality suppliers. Differently from current literature, experimentation capacity has been here supposed, kept and analyzed distinguished from exploration. By testing six hypotheses concerning the differential or combined effects of exploration and experimentation capacity, it is shown that, lacking agents' sophisticated forms of learning, exploration capacity has no any positive effects on industry competitiveness. Moreover, in presence of agents' full opportunism, it has the negative effect of dramatically increasing uncertainty and instability. Conversely, experimentation capacity improves performance conditionally to competitive pressure, because when the number of transactions exceeds that of suppliers its marginal benefits decrease and instability increase.

Key-words: agent-based models, decision making processes, experimentation, exploration, opportunism.

JEL code: C150, D230, D830.

1. Introduction

Out of mainstream economics heaven, where agents have unbounded or extremely high rationality (and thus, unbounded knowledge), industry and firms competitiveness depends, among many other factors, on agents' searching and experimenting capacities (Cyert and March, 1963; March, 1988, 1991; Simon, 1991). They both represent specific forms of bounded rationality (Simon, 1982, 1997). Instead of matching the ideal requirements of Bayesian probability updating and regression estimation, agents' learning likely occurs by means of rule or routines following, represented by their (more or less intentional) decision making processes (March, 1988, 1997).
In this paper, through an agent-based simulation model of a three-segments industry some structural and cognitive characteristics of agents' searching, choosing and learning have been operationalized, its effects on industry competitiveness analyzed, and a set of related hypotheses tested. Cognitive characteristics enable agents to explore their competitive environment, and are based on their computational capacity, which consists: i) in gathering and comparing various amounts of information required to select the best quality suppliers; ii) in building and updating their memory, which notwithstanding is affected by various types of forgetfulness effects. Structural characteristics consist in different levels of outsourcing, which allow agents experimenting and testing the truth and usefulness of their information. Their behaviour is path dependent and they learn in a basic, substantial though not sophisticated sense.
Virtual experiments examine also two more variables: i) a structural one, which distinguishes the performance of final producers (FP) and first tiers (FT); and ii) a cognitive one, which refers to agents' cheating attitude at the opposite extremes of full honesty or dishonesty. Since it is supposed that in this industry competitiveness is strictly related to product quality and this latter to suppliers' quality, agents' main goal is selecting the best suppliers. Performance parameter is average quality, measured at the aggregate level of each segment. A set of virtual experiments is run distinguishing the cases of honest and opportunistic agents, who always lie when consulted by their competitors about suppliers' quality.

This study exploits the architecture of CIOPS model, which is a network of agents representing firms that interact through structural and cognitive links. The structural network is a productive system constituted by agents connected each other by (vertical) economic relationships, and interacting through orders and products. Conversely, information flows horizontally among agents of the same filiere segment. Industry is taken in a medium (200 firms) size, and sales and profits of FP depend on the quality of FT, which in turn depends on that of their suppliers (the segment of raw materials). It is supposed that clients always can sell products on the final market, and select subcontractors but not vice versa.
Cognitive variables are: type and amount of information available to agents, their rationality (computational capacity, forgetfulness effects, and levels of aspiration), their types of decision making processes, and attitude to cheat. Agents' decision making process is constituted by four types of choices that are compared each other in each step: random choice (RND), direct (DEBT) and indirect (INDEBT) experience-based, and reputation-based (REBT). Clients ask other agents information concerning suppliers quality, and compare it with that existing in their memory. This way they move within information space, while their learning is undermined by some forgetfulness effects. Moreover, their rationality is bounded also by the limited number of information they can ask. In essence, there are two dynamic networks, a structural and a cognitive one, which overlap and interact in multiple ways, and each agent develops his own cognitive representation of the structural network.
The paper proceeds as follows. In next section some hypotheses are raised as concerning the effects of explorative and experimenting capacity on the level and stability of industry competitiveness in terms of average quality. These effects are analyzed in a context of honest or opportunistic behaviors. In section three the simulation model is described, and the parameters of virtual experiments are summarized. Then, in the next section results are discussed and analyzed in terms of final outcomes after 400 simulation steps, and in terms of dynamic patterns.

2. Hypotheses

It is commonly acknowledged that trust is a crucial competitive factor at firm and industry level (Lane and Bachmann, 1996, 1998). In fact, if agents behave opportunistically, they can, among other forms of opportunism (Williamson, 1996), lie as concerning economic or social issues. If asked by a competitor regarding his best suppliers and if this is a critical factor of success, opportunist agents cheat to damage their competitors. Hence, it is possible to advance the following:

Hypothesis 1: In industries characterized by cheating agents performance is significantly lower than in industries with honest agents.

According to most management literature (March, 1997; Simon, 1997) and behavioural (Dosi and Marengo, 2007; Rizzello, 2003), and evolutionary economics (Langlois and Everett, 1994; Witt, 1993), agents' abilities are bounded and there is no –at least, no complete- knowledge of the environment. It is commonly argued (March, 1991) that the extent of its exploration depends just on those abilities, and that they heavily affect agents' and industry competitiveness. Indeed, following March (1991), literature on fitness landscape (Auerswald *et al.*, 2000; Chang and Harrington, 2006; Ethiraj and Levinthal 2004; Frenken, 2006; Gavetti and Levinthal, 2000; Levinthal, 1997; Levinthal and Warglien, 1999; Levitan *et al.*, 2003) and routines (Cohen and Bacdayan, 1994; Egidi, 1996; Feldman, 2000; Feldman and Pentland, 2003) includes experimentation into exploration activities. However, this inclusion brings the risk to mix too diverse activities, like search, variation, risk taking, experimentation, play, flexibility, discovery, innovation (March, 1991: 71). If all components moved towards the same direction, this crowded set would be just a useful approximation, but if, instead, these activities determined very different outcomes, then it would be necessary to make distinctions. Actually, they identify very different operations, located into different positions and functions within organizations. Therefore, if there is no sound reason to argue that exploration and experimentation capacity have the same effects on performance, it is quite reasonable to suppose that its effects are different, and eventually combined in a nonlinear way. Thus, the following two hypotheses could be raised:

Hypothesis 2a: Exploration and experimentation capacity contribute differently to improve performance.

Hypothesis 2b: The positive effects of exploration and experimentation capacity add its effects in a likely nonlinear way.

Among the many components and characteristics in terms of which rationality can be analyzed there is that of exploration capacity, which here is represented by three agents' computational capabilities: i) to gather information from others by asking them who are the best suppliers according to their own experience or to reputation they have accessed; ii) to compare this information with their own experience; and iii) to choose the highest values taking into account informers' reliability and suppliers' availability. All these abilities are collected and measured in terms of the number of questions agents can handle. Hence, it can be raised the following:

Hypothesis 3: A substantial increasing of exploration capacity (measured in terms of number of questions) improves performance in terms of either higher average quality or speed to reach the highest degree of average quality.

Cognitive agents (Carley, 1986, 1989; Carley and Newell, 1994; Sun, 2005) have not only the property of bounded rationality, but also that of manipulating information according to their convenience or social habit. Therefore, they can have different inclination to trust and lie (Prietula, 2001). If cheating is intended as a gap of true information, then more computational capacity should help more in presence of cheating rather than honest agents, because it is supposed to reduce the lack of true information. This disclosure occurs indeed through the discovery of dishonest informers (agents). This leads to suggest the following:

Hypothesis 4: Performance improvement due to higher exploration capacity is more relevant in industries characterized by cheating rather honest agents.

Recent studies in management science and evolutionary economics underline that the effectiveness of searching processes depends not only on exploration, but also on agents' experimentation capacity. It is usually assumed that it significantly affects performance (for instance, environmental fitness) improvement, because direct experience implicitly tests the expectations created through the various forms of decision making. Experimentation capacity is here operationalized in terms of outsourcing degree, because it enlarges the area of direct experience. If the same volume of purchase is split among many suppliers, clients access more knowledge concerning suppliers' quality, and this in turn allows them improving further selections. The degree of outsourcing indirectly acts as a test of clients' cognitive maps likelihood, and so it helps addressing their future choices. Hence, it can be advanced the following:

Hypothesis 5: A substantial increasing of experimentation capacity (measured in terms of number of subcontractors per each agent) improves performance in terms of either higher average quality or speed to reach the highest degree of average quality.

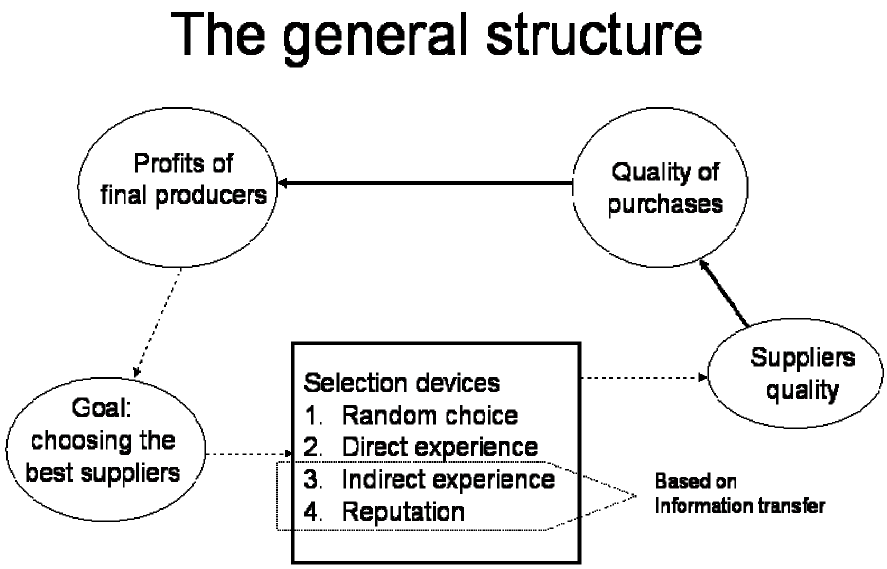
Analogously to what supposed for computational capacity, if cheating is intended as a gap of true information, then more exploration capacity should help more in presence of cheating rather than honest agents, because it is supposed to reduce the lack of true information. This leads to suggest the following:

Hypothesis 6: Performance improvement due to higher experimentation capacity is more relevant in industries characterized by cheating rather than honest agents.

3. Model structure

A general view of the model (fig. 1) shows its logical structure: profits of final producers depend on the quality of their purchases, which in turn depends on suppliers quality. Thus, the goal of final producers is to choose the best suppliers. Since final producers don't know suppliers quality, they have to select them through one of four selection mechanisms: random choice, direct experience, indirect experience, or reputation. The latter two imply information transfer between final producers, who play the role of reciprocal informers.

Fig. 1



The major points of interest of this model are in the characteristics of agents and in the ways in which they affect their selection mechanisms. Agents are trustworthy of variably opportunistic, and they act this latter behavior through a certain propensity to cheat. This represent the main threaten to the individuation of the best suppliers, and consequently to the achievement of high profits. Moreover agents are boundedly rational, in that they have computational limits: they recognize only a limited number of agents and can ask only a limited number of questions, and they suffer of forgetfulness effects. Finally, they are satisfiers and not maximizers, and exchange information only among them and not with FT.

Suppliers are selected according to their quality. However, actual suppliers' quality is verified only after transactions, because clients either could not know it in advance or they could have incorrect information. In this model information reliability is not evaluated as such, but instead it depends on informers' reliability. Actual suppliers' selection depends on clients' experience and cognition: knowledge, computational capacity, expectations, and decision making processes.

In order to choose their subcontractors clients: i) scan their own memory on past direct and indirect experience with suppliers, ii) ask other agents as informers, iii) check the existence of any reputation built on the information passed by informers. Notice that questioners are allowed to ask information only to members of their segment.

Questioners' analysis of informers' trustworthiness leads to set up a list including only full reliable informers. If the number of informers entering the list is minor than the number of questions that the questioner is able to ask, in this case the questioner asks also some unknown informer randomly

chosen. The number of questions that the questioner is able to ask represents his exploration capacity, which is examined at various levels: 4, 16, 40, and 80. It is kept uniform for all clients, and constant during the whole virtual experiment.
Informers' trustworthiness depends on the truth of information that that informer passed previously to the specific questioner. If, in the past, a given questioner followed the indication of a given informer, then the questioner could verify informer's reliability. Specifically, reliability is defined as the absolute value of the difference between suggested quality and actual quality of a specific supplier. An informer is maximally reliable -reliability 1- when the gap between expectation and actual outcome is zero. Conversely, this degree lowers to zero, according with the formula:

$$1-| Q_{is} - Q_{as} |$$

where:
Q_{is} = supplier *S* quality indicated by informer *i*,
Q_{as} = supplier *S* actual quality.
Unknown informers are assigned maximum trustworthiness value, as it is also for the required level of informers' reliability. Informers can tell truth or falseness depending on their inclination toward cheating. True informers indicate the best supplier among the ones directly experienced, and the ones of which they know reputation. False informers indicate the worst supplier as if it were their best. That is, cheaters say that the worst has the quality of their best. Regardless whether true of false, informers always specify the nature of their information, whether from direct experience or reputation. There is no answer when informers have none of the two sources of information.
Agents have an inclination towards cheating, as the probability that in each interval is given false information, and it is kept constant during the virtual experiment. If the attitude is zero, then agents pass always true information, and vice versa. It is crucial to underline that cheating concerns only the content and not the type of information. In other words, informers can indicate their worst bad experience as if they were the best, but they cannot say, for instance, that they have direct experience if they don't, or any other kind of falsity concerning the source of the information they pass.
As concerning reputation, it is acknowledged as such by a given questioner when his informers' evaluation of a given supplier converges on a strict range of values. Such an acknowledgement is not contingent, because it implies informers' memory. Thus, reputation is formed by reaching the critical mass of a number of questioner's previous indirect experience. Moreover, once reputation occurs, it can be also transmitted from informers to questioners. Thus, while the origin of reputation is based on informers' answers convergence, then it could be quickly passed to other agents through communication processes. This is the only form of gossip working in this model, because informers don't take the responsibility of the reputation passed to clients.
Agents build their own cognitive network by coping with a number of direct experiences and getting information from others. Through their direct experience agents get information on suppliers' actual quality and informers' reliability by interacting with the given supplier. Indirect experience-based information originates from informers' direct experience, while reputation-based trust can derive either from informers who signal it as reputation or as converging indirect experiences.
Through exploration and experimentation routines agents collect and verify a set of INDEBT and REBT information, which are stored in their cognitive network in order to build and update their memory. If confirmed by experiments (direct experience), that part of memory made of INDEBT and REBT information becomes DEBT. Experimentation concerning INDEBT information and memory gives a feedback on the reliability of the agents who gave it, and of course on the corresponding suppliers quality. However, all the types of memory are weakened by some forms of forgetfulness, which concerns information inactivated for long time: after 100 intervals of inactivated direct experience, 40 steps of inactivated indirect experience, and 60 of reputation the

corresponding information dissolves. Similarly, non consulted informers for more than 60 steps disappear from questioners' memory.

What do agents do? Agents are all equal in cognitive terms, and respect to goal seeking and expectations. In each virtual experiment they are facing the same environment and are provided with the same opportunities. They are equal also under structural respects, with the exception that first and second (source) tiers are randomly assigned a given quality, and that to FP and FT certain initial opportunities are randomly offered.
Agents differ on which type, how much and how reliable is their knowledge. Knowledge at industry level is just the sum of agents' knowledge, but not all knowledge circulates. For instance, in those configurations in which direct experience is prevalent, and especially in which indirect experience is inhibited, transferred knowledge is only a small portion. Noticeably, though their simplicity agents store and transfer different types and amount of knowledge. Moreover, they develop different images of the others, and so they enact different cognitive networks.
As concerning trust and opportunistic behaviors, agents' attitude could be defined as "prudent trust" in the sense that they trust others but check their information and keep track of the corresponding result. Though they do not necessarily react through pure forms of retaliation, once an informer has been recognized as unreliable, they cancel him from the list of future potential informers. Hence, even if their reactions to cheating are "soft" and only passive, agents are not "blind trustees", because they check information and learn consequently. Moreover, it should be noticed that agents acquire free information, because it has no price and informers cannot refuse to give it. Finally, it should be taken into account that in this model all these cognitive operations are costless. In short, there are no direct costs of misplacing trust or checking information coming from indirect experience or reputation.
However, though there are no such direct costs, "prudent trust" has an indirect cost, that turns to produce effects on performance: at least in consequence of the first lie received from a cheating informer, the questioner is addressed to a bad supplier, and thus, his own performance is damaged. Being industry performance simply the sum of that of individual agents, industry profitability is negatively affected. In this model reputation-based trust is more "insidious" and dangerous, because, for it does not imply informers' responsibility, the recognition of its eventual falsity does not lead to reject the informer who passed it. Therefore, that informer can again produce damages to that questioner.

Configurations of virtual experiments. Parameters and initial conditions used in these virtual experiments[1] are shown in table 2. In each step a whole cycle choice/order/production/payment takes place. Supposing that it can represent a reality in which it lasts 5 working days, 400 steps describe 10 years of industry evolution from the very beginning. This could approximate a simple-product industry, whose production cycle is very short and can be realized completely in one week, but whose quality represents a competitive advantage. Medium-high quality segments of some consumer goods markets like clothing, footwear, leather, etc. could satisfy these characteristics. The time span consideration is very important to give sense results of dynamic patterns, because while in some cases performance stabilizes already before 50 steps, in many other situations it still remains uncertain after 400 steps. Sometimes performance becomes definitely unpredictable in the short run, while in the long run keeping stable around a mean value.
Indeed, complex products would better match the crucial role assigned suppliers' quality, as it is characteristic of biotechnology, aerospace, biomedicals, and most high-tech industries. However, they have production cycles extending far beyond two or even six months, and they require even

[1] The program running the model will be available on the URL of Knownetlab Research Center (www.knownetlab.it). To run the program is needed the platform and language LSD (Laboratory on Simulation Development), placed at www.business.auc.dk/lsd. Authors are available to give any support to use it.

long time to define product and contractual characteristics. If such a real correspondence is given each step, it is clear that even 50 intervals addresses to a very significant time span.
Experiments are executed varying: i) number of questions asked to informers (4, 16, 40, 80); ii) outsourcing degree (1, 2, 4 or 8 subcontractors for each client); and iii) agents' inclination to cheat (0 or 1), while keeping constant other parameters. Thus, 32 virtual experiments are here analyzed both for honest and cheating agents. Due to the high number of variables and the value that each variable may assume for each agent, within each virtual experiment suppliers differ only in quality while keeping constant other parameters, and agents have the same quality threshold, employ the same decision making *pattern* (which is composed by the four decision making *processes*: random, direct and indirect experience-based, and reputation-based), and have the same inclination to cheat.
Other parameters not specifically discussed before are the following:

- quality threshold: this refers to agents' aspiration levels (Simon, 1982, 1997), who consider a supplier satisfying only if his quality is not lower than 0.75;
- clients' requirement of informers' reliability, which here it is supposed to be full reliability. In other words, an informer is supposed to be credible only if he is completely reliable;
- reputation threshold, which indicates the number of convergent information to form reputation. In these experiments it is required that at least 4 agents (including the questioner) give the same evaluation, with an approximation of 10%.

Tab. 1 **Virtual experiments parameters**

Structural parameters with constant values	
Filiere segments	3
Industry size	200 firms
Ratio FP/FT = 1/2	40 downstream firms, 80 suppliers in intermediate segment and 80 suppliers in upstream segment.
Quality	Randomly uniform distribution between 0.5 and 1
Maximum Average Quality (AQ) with 1 supplier per client	0.88
Maximum AQ with more than 1 supplier per client	up to 1.0, depending on the configuration
Minimum AQ with 1 supplier per client	0.63
Minimum AQ with more than 1 supplier per client	up to 0.50, depending on the configuration
Cognitive parameters with constant and uniform values	
Decision making processes	RND, DEBT, INDEBT, REBT.
Quality threshold	0.75
Clients' requirement of informers' reliability	1
Number of convergent information to form reputation	4
number of intervals to forget inactivated DEBT	100
number of intervals to forget inactivated INDEBT	40
number of intervals to forget inactivated REBT	60
number of intervals to forget inactivated informer	60

Varied structural parameters	
Outsourcing degree as a measure of experimentation capacity	1, 2, 4, 8, subcontractors for each client
Varied but uniform (among agents) cognitive parameters	
Number of questions as a measure of exploration capacity	4, 16, 40, 80
Inclination to cheat	0 or 1

In this paper only the whole industry performance is investigated, that is single firm's course is not examined. Therefore, the main index is industry average profit (labeled as AP). Since in sequential technology FP are client of intermediate firms that on their own buy products from upstream suppliers, it is possible and interesting to keep distinguished FP and FT average profit. It is important to point out that: i) when required to deliver their products, FT previously check whether they can find a satisfying and available supplier (second tiers) on their own. If not, they do not accept any engagement and stay inactive in that interval; ii) exploration and experimentation capacity assigned to client hold for FT too, because they act as such respect to the segment of second tiers.

4. Main results

The first hypothesis suggests that industry performance in terms of average quality is severely damaged by agents' opportunism expressed by full cheating attitude. Results confirm it (tab. 2a, b, and c), because cheating agents' performance is considerably lower than that of honest agents in all combinations between exploration and experimentation capacity, and in both industry segments. Losses range from 0.06 in an industry with two subcontractors per client and 40 questions handled, up to 0.14 in an industry with 8 subcontractors and only 4 questions available.

Tab. 2a **Performance (in terms of average quality) in each segment**

No Cheaters

	Final Producers				First Tiers			
N of questions / N of suppliers per FP	**1**	**2**	**4**	**8**	**1**	**2**	**4**	**8**
4	0,88	0,92	0,94	0,95	0,87	0,85	0,84	0,83
8	0,88	0,92	0,94	0,94	0,88	0,85	0,85	0,83
16	0,87	0,93	0,95	0,96	0,88	0,86	0,85	0,85
40	0,88	0,93	0,94	0,93	0,88	0,85	0,86	0,85

Tab. 2b

All Cheaters

	Final Producers				First Tiers			
N of questions / N of suppliers per FP	**1**	**2**	**4**	**8**	**1**	**2**	**4**	**8**
4	0,79	0,83	0,81	0,80	0,79	0,78	0,76	0,73
8	0,79	0,83	0,81	0,81	0,79	0,78	0,76	0,76
16	0,79	0,82	0,79	0,78	0,79	0,79	0,77	0,74
40	0,78	0,85	0,79	0,76	0,79	0,79	0,77	0,77

Tab. 2c **Tab. 3a – Tab. 3b**

N of questions / N of suppliers per FP	Final Producers 1	2	4	8	First Tiers 1	2	4	8
4	-0,09	-0,09	-0,13	-0,14	-0,08	-0,07	-0,08	-0,10
8	-0,09	-0,10	-0,13	-0,13	-0,08	-0,07	-0,09	-0,07
16	-0,09	-0,11	-0,16	-0,18	-0,09	-0,07	-0,08	-0,11
40	-0,09	-0,08	-0,15	-0,16	-0,09	-0,06	-0,08	-0,08

The second hypothesis suggests that: (a) exploration and experimentation capacity contributes differently to improve performance; and (b) its positive effects add in a likely nonlinear way. Hypothesis 2a is confirmed (tab. 3a and b), because actually exploration capacity does not add any improvement while experimentation capacity remarkably does. Moreover, the differential increment of performance is decreasing, confirming its nonlinearity. However, these positive effects can be seen only for honest FP and at the first increment for dishonest. In all other cases effects are negative.
The second part of this hypothesis is confirmed too, though for a surprising reason: the combined effects of exploration and experimentation capacity is negative in most cases, excepted those in which the former is irrelevant. In other words, besides the early three degrees of outsourcing (1, 2 or 4 subcontractors per client) for FP in which exploration capacity does not matter, in all other combinations it plays reducing and not increasing performance.

Tab. 3a **Performance increasing by outsourcing increasing**
No Cheaters

N of questions / N of suppliers per FP	Final Producers 2	4	8	First Tiers 2	4	8
4	5.08%	1.92%	0.63%	-3.00%	-1.16%	-0.84%
8	5.18%	1.36%	0.10%	-2.99%	-0.16%	-1.82%
16	5.49%	2.76%	0.52%	-2.46%	-0.34%	-0.60%
40	5.35%	1.02%	-1.02%	-2.74%	0.51%	-0.58%

Tab. 3b **All Cheaters**

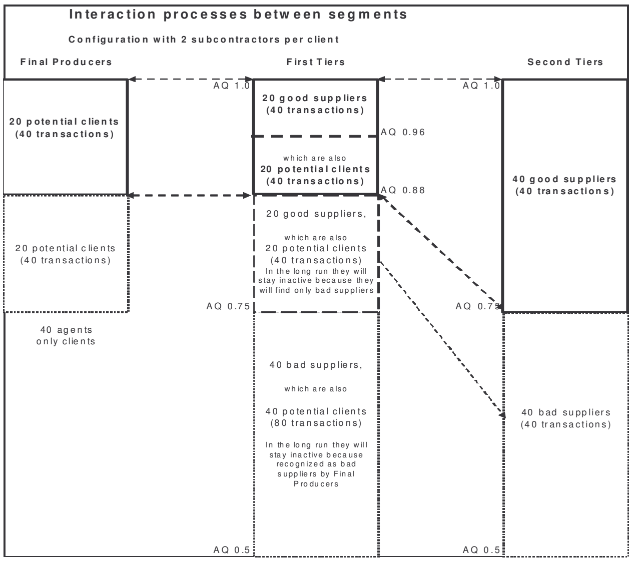
N of questions / N of suppliers per FP	Final Producers 2	4	8	First Tiers 2	4	8
4	4.86%	-2.25%	-0.87%	-1.45%	-2.96%	-3.42%
8	4.88%	-1.84%	0.00%	-1.50%	-2.22%	0.00%
16	4.19%	-3.17%	-1.97%	-0.55%	-1.98%	-4.57%
40	7.53%	-7.06%	-3.59%	0.53%	-2.39%	-0.78%

The third hypothesis argues that a substantial increasing of exploration capacity improves performance in terms of either higher average quality or speed to reach the highest degree of average quality. Data shown in tab. 2a (column 1 and 5) reject this hypothesis, because in both industry segments performance does not significantly change while progressively doubling exploration capacity from 4 to 8 to 16 questions. Even increasing it ten times nothing changes, though this case is particularly instructive because each agent is able to handle information from all the others in each interval. That is, this situation corresponds to the maximum questioning and deciding capacity.

Quite surprisingly, the same happens also with cheating agents: higher exploration capacity is not able to neutralize the losses due to opportunistic behaviors. This is due to the fact that the various forms of forgetfulness periodically cancel the various types of memory, so preventing the full knowledge of bad suppliers and false informers. When experimentation capacity keeps constant to one supplier, then exploration capacity does not help unmasking false informers. It just help accumulating knowledge. Hence, the fourth hypothesis should be rejected.

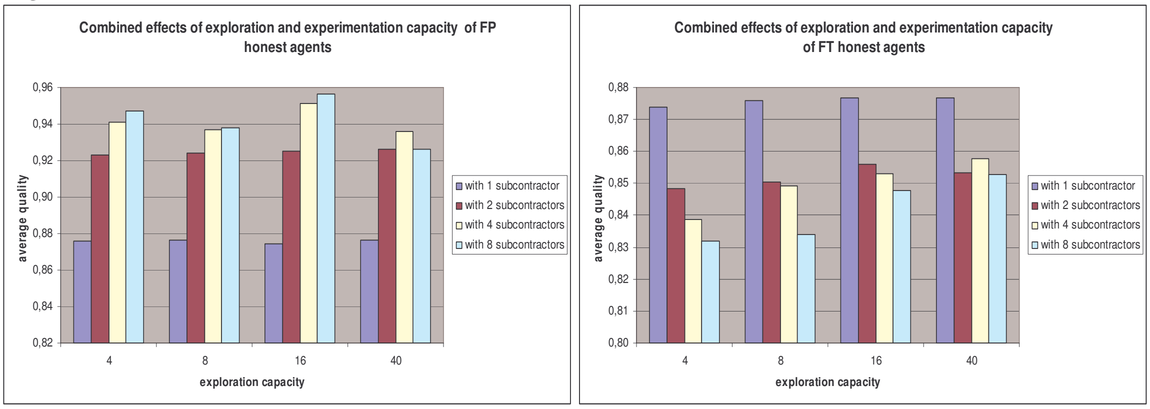
The fifth hypothesis states that a substantial increasing of experimentation capacity improves performance in terms of either higher average quality or speed to reach the highest degree of average quality. This hypothesis is only partially confirmed, because it records opposite results in the two segments. By doubling the number of subcontractors per each agent from 1 to 2 and then to 4 and 8 FP performance remarkably grows (tab. 2a and fig. 3a). Though double of FP, FT are all activated when the outsourcing degree is more than 1, and this leads to reach maximum performance (fifth column of tab. 2b). Surprisingly, performance lowers when FT subcontractors ratio (experimentation capacity) increases (fig. 2b). This is due to the fact that forgetfulness effects heavily hinder performance growth. In the case of low explorative capacity (fig. 6), as performance starts growing sharply with 1 subcontractor between 55 and 80 steps, forgetfulness effects damage searching process of good suppliers. In 30 steps they bring performance almost to the level corresponding to random choice (0.75). Though over time these effects are less severe, they keep performance always very low.

Fig. 2



What is further noteworthy is that extended experimentation capacity brings average quality far beyond the maximum level corresponding to the case of just 1 subcontractor per firm. It means that proportionally more exchanges do occur with good quality suppliers, but this is obtained at the price of reducing the quantity of active agents (fig. 2). In fact, though FP are half FT, and therefore activate only half FT, once FP have more than 1 subcontractor they try to order products to all FT. Before accepting, these latter check whether they can find satisfying and available suppliers. However, since second tiers are given the same quality distribution between 0.5 and 1.0, half of them are not good. Consequently, half FT cannot work, and these are the bad quality suppliers, because in the long run only the good ones will be required to work by FP. In conclusion, the 40 FP over time will not realize all their 80 transactions, but the successful ones will have a higher quality. The final result of the complex feedback processes between agents with the pivotal role of FT, who are at the same time single transaction suppliers and double transactions clients, is the following: 20 FP and 60 FT fail; FT average quality keeps constant and that of FP substantially increases.

Fig. 3 (a) (b)



Nearly the same result occurs with cheating agents (tab. 4a and b, and fig. 4a): higher experimentation capacity of FT does not compensate opportunistic behaviors, which remains lower than that of FP, though with a gap lower than that characterizing the difference between honest agents. This leads to partially reject hypothesis five, which in fact is confirmed only concerning FP. Here results are more complex to be interpreted, because they show a considerable performance increasing by doubling the number of subcontractors from 1 to 2, followed by a slight decreasing with further doublings. This situation can be explained by comparing the absolute number of clients and suppliers. Since they are in a 1 to 2 ratio, giving 2 subcontractors per client means equalizing their absolute quantity. It means allowing clients a full experimentation of suppliers, and presumably improving their performance. Further increasing of subcontractors number gives raise to another effect: when competing for a smaller absolute number of suppliers and lacking correct information about their quality, the net effect at whole level is hindering further improvements, and eventually lowering global performance. The particularly high performance improvement occurring in the case of 40 questions with two subcontractors would be due to the combined effects of both forms of explorative and experimentation capacity, that are maximal in each case. Moreover, beyond 2 subcontractors per client the number of transactions would exceed that of transactors, and so this would activate negative effects of high competition among clients. Good suppliers, that is those with a quality more than 0.75, would become a scarce resource, and hence clients would be easily diverted by cheating informers towards bad suppliers. Trend analysis in next section will clarify this point.

Being already in a one-to-one ratio with their suppliers, FT do not benefit of the same effect occurring to FP with 2 subcontractors. This explains why performance decreases in any configuration with more than one subcontractor (fig. 4b). The small “anomaly” of the case with 2 subcontractors and 40 questions is probably due to the effect of high sensitivity of this set of configurations to initial conditions. In fact, as will be discussed in next section, exploration and experimentation capacity and cheating behaviors amplify oscillations even when taken singularly. The effect is dramatically emphasized when all the three conditions are combined.

Tab. 4a **First Tiers minus Final Producers**

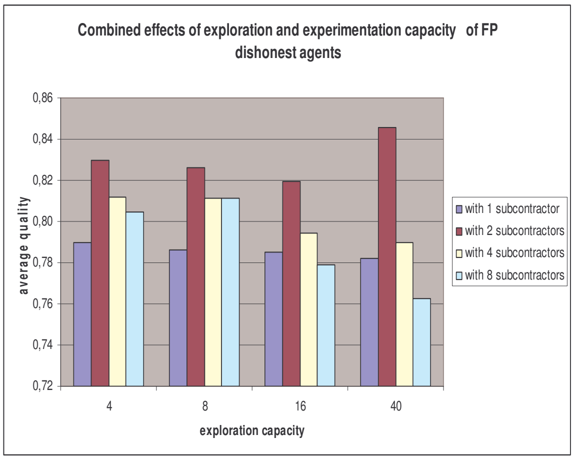
No Cheaters

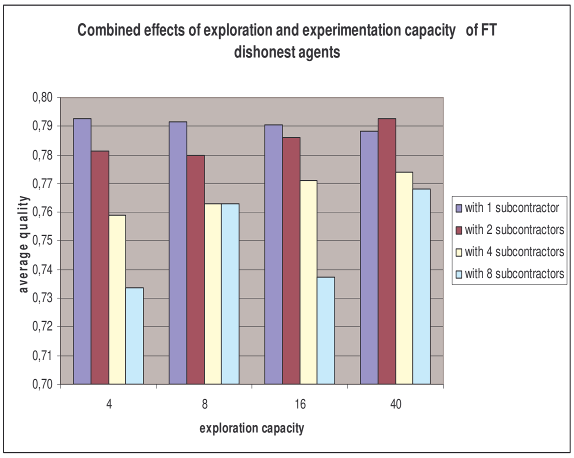
N of questions	N of suppliers per FP	**1**	**2**	**4**	**8**
4		0,00	-0,07	-0,10	-0,12
8		0,00	-0,07	-0,09	-0,10
16		0,00	-0,07	-0,10	-0,11
40		0,00	-0,07	-0,08	-0,07

Tab. 4b

N of questions	N of suppliers per FP			
	All Cheaters			
	1	**2**	**4**	**8**
4	0,00	-0,05	-0,05	-0,07
8	0,01	-0,05	-0,05	-0,05
16	0,01	-0,03	-0,02	-0,04
40	0,01	-0,05	-0,02	0,01

Fig. 4 (a) (b)



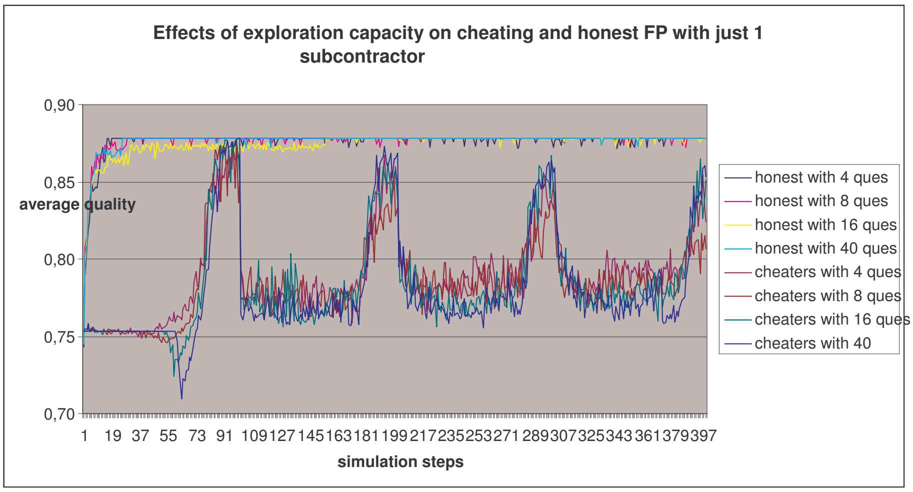


5. Dynamic patterns

Dynamic patterns of previous configurations are sometimes very different, even when the average quality at the 400th interval is very similar. The superfluous influence of different levels of exploration capacity for both honest and dishonest agents, and the sharp diversity of performance between the two regimes FP is shown in fig. 5. What it is noticeable is that while the former reaches stability at maximum level already between 20 and 40 steps, with very small oscillations due to forgetfulness, the performance of industry with dishonest FP is very uncertain and worst. After starting, it remains until 55th step near 0.75, which is the value of simple random choice. Then, notwithstanding some negative effect of INDEBT, REBT and informers' forgetfulness, which heavily but shortly damages performance of agents with 16 and 40 questions of exploration capacity, performance rapidly and sharply increases. However, every 100 steps DEBT forgetfulness destroys performance, and this pattern repeats periodically regardless of agents' explorative capacity.

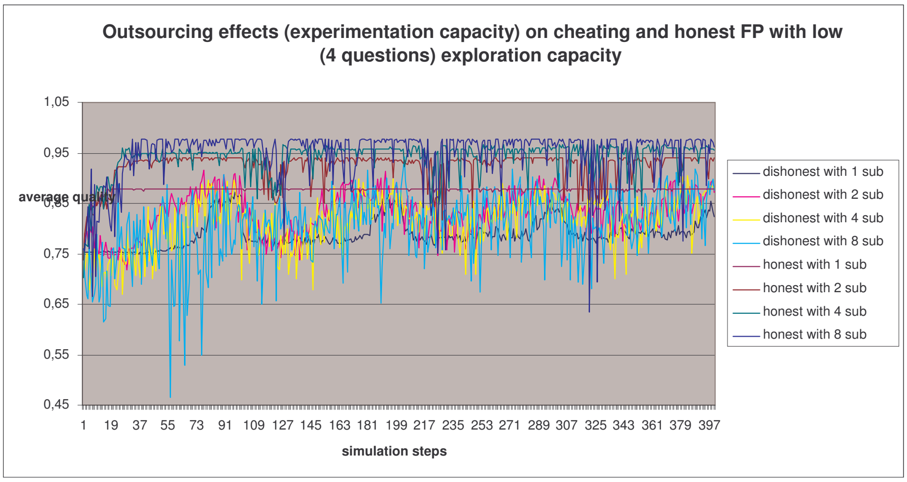
However, in order to correctly interpret dynamic patterns it should be bear in mind the sense of time span in a likelihood correspondence with reality. If a step represented a working week, the industry with honest agents would reach stability at maximum performance around one year, while in the situation with dishonest agents, whatever their exploration capacity were, performance would remain definitely low and unstable even after 20 years. Paradoxically, if agents would be so intelligent to understand that everybody always cheats it would be convenient to do not care any information and follow only their own experience. Even systematic random choice would be more convenient than trusting or testing others' information, because at least they would not spend time and resources in environment exploration (gathering, comparing and testing others' information). In other words, they would save a lot of computational capacity.

Fig. 5



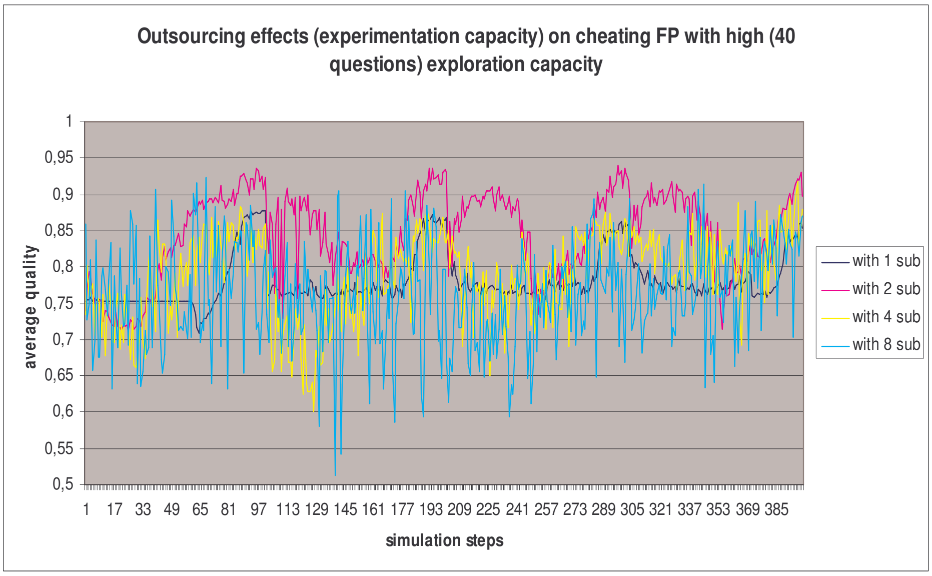
Besides dramatically increasing performance for both honest and dishonest agents explorative capacity has also the negative effect of making dynamic patterns highly unstable (fig. 6 and 7). Almost half time is spent during more or less wide shocks, due to competition between clients to find the best suppliers, and also to the fact that forgetfulness effects distribute and overlap in a rather unpredictable way. The situation is much worst if agents lie (fig. 7): besides lower average quality, instability sharply increases. Finally, it can be noticed here in negative the same effect that in positive brings average quality far beyond the limit of 0.88. In fact, some values drops down below 0.63, due to the fact that some client cannot avoid to work with only bad subcontractors.

Fig. 6



The negative effects of combining high exploration and experimentation capacity on full cheating FP is shown in fig. 10. Here dishonest agents have the maximum explorative capacity of asking all potential informers, which gives the only relevant effect of increasing instability. This effect is emphasized by the fact that agents coordinate their selection strategy. In other words, the searching process of each subcontractor benefits from the memory accumulated respect to other subcontractors.

Fig. 7



Conclusion

Five general conclusions can be drawn from this study. The first one is that, when information is freely accessible, opportunistic behaviors in the form of cheating severely damage industry competitiveness. The second one is that exploration and experimentation capacities have different effects on performance, and that its combination can have rather surprising outcomes, depending on structural and cognitive characteristics. Thus, it seems correct to keep and analyze separately these two activities.

The third result is that exploration capacity, even if supported by the whole required computational capacity, does not help compensating such performance losses. In fact, when agents cheat, gathering more information and making more calculations does not lead to make better choices. This finding tells us that increasing exploration capacity by means of pure computational capacity is not sufficient to make exploration effective in facing with opportunistic behaviors. More advanced forms of rationality and learning would be required, enabling agents choosing among decision making processes instead of single choices. In Bateson's words (1972), agents would need level-2 learning. In fact, as this study demonstrates, choosing the best choice and avoiding unreliable informers is not enough to achieve satisfying performance even after 20 years (400 steps) of working life in a simple-technology industry. Likely, to achieve better performance agents would need to assume as object of computation not single information comparison and single informers' reliability, but rather *sets* of choices with its associated decision making processes and *sets* of informers with its specific behaviors.

The third main finding is that experimentation substantially improves performance both with honest and opportunistic behaviors. In the latter case this positive effect is due to the fact that experimentation increases also the share of direct experience, hence improving the effectiveness of controlling false information. However, once the number of transactions exceeds that of suppliers, then the marginal benefit of experimentation decreases, and uncertainty and instability sharply increases because of competitive pressure. Moreover, lacking forms of advanced learning processes, performance improvements reached through experimentation are achieved at the price of higher instability. Finally, with dishonest agents adopting these simple decision making processes higher exploration capacity produces instability instead of performance improvements.

The fifth interesting conclusion regards the key-role played by FT in a context of honest agents. If their competition increases, then their average quality keeps constant, while that of FP grows significantly. Hence, to the extent that profit depends on quality, it means that industry quality competitiveness and profitability substantially improve. However, the side effect –eventually wishful, in a perspective of increasing industrial efficiency by pushing competition- is that 2/3 of FT and 1/2 of FP do not work any more in the long run. Conversely, if agents cheat, the same increasing of FT competition implies a similar sacrifice in terms of firms failures, which is not compensated by an industry performance improvement.

The major limitations of this work concern some parameters setting and architectural features of the model. There are aspects increasing and others decreasing stability and efficiency. Among the former there is the invariance of agents' behavior in terms of cheating, that is the fact that they do not change their cheating attitude makes them very efficient in selecting suppliers. If behavior could change their strategies would be subjected to much more uncertainty and hence the whole industry would attain lower and later average profits. The introduction of exploration and experimentation costs, and of advanced forms of learning processes would certainly add interesting aspects to this analysis. Moreover, it is not implemented any strategy of building inter-firm networks, which also had to stabilize and maybe improve industry performance. Finally, the introduction of mortality and natality mechanisms would also substantially enrich the model. It would become more useful for predictions and empirical validation, and would add room for more complex evolutionary patterns.

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