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Opportunism by cheating and its effects on industry profitability. The CIOPS model

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Abstract CIOPS (Cognitive Inter-organizational Production System) is an agent-based model that integrates industry structural aspects and agents' cognitive characteristics. A demand-driven industry, whose profitability depends on the quality of suppliers' products, is represented by a three-stage vertically integrated industry. Four types of decision-making patterns are analyzed and confronted each other: from the simplest one (random choice) to the most complex one, which includes direct and indirect experience and reputation. They operate as selection devices supporting agents to select the best suppliers. Requiring agents' communication, indirect experience and reputation could be influenced by eventual opportunist behaviors. As the disturbing effect of falsity depends also on the size of decision and information space, the CIOPS model simulates different situations. Even though submitted to some restrictive assumptions, by testing five groups of hypotheses CIOPS model enables to fix many points that could be tested by empirical data and further developed by relaxing the assumptions. Results show that, especially in presence of reputation-based trust, cheating attitude severely damages industry profitability and the enlargement of information space dramatically strengthens the negative effects. Though indirect experience and reputation-based trust are powerful tools to improve industry profitability, when people cheat they dramatically reverses its effects. A sharp performance diversity is also evidenced between industry segments, because firms in the first tiers segment, who are also the suppliers of final producers, perform much better and more efficiently than final producers. Though industry size growth determines the negative

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effect of reducing performance, it produces the positive effect of shortening the time to reach the highest profitability and to stabilize it. Finally, it is also demonstrated that cheating half times determines almost the same negative impact of cheating always.

Keywords Agent-based models · Decision-making processes · Industry profitability · Opportunism · Reputation · Supplier-buyer relationships · Trust

1 Introduction

A large and growing literature in various disciplinary fields, like economics, management, and sociology, addresses the role played by socio-cognitive variables in industry and firm competitiveness. The most significant effects are often attributed to trust (Child 1998; De Jong and Nooteboom 2000; Humphrey 1998; Lane 1995; Lane and Bachmann 1996; Oleinik 2005; Sako 1998), opportunism (Williamson 1975, 1985, 1993), and reputation (Hall 1992; Horner 2002; Martinez and Norman 2004). Because of the usual difficulties to compare and generalize empirical findings and to find crucial cases able to test theoretical hypotheses, this research area could substantially benefit from the development of virtual experiments. To this aim has been developed CIOPS (Cognitive Interorganizational Production System), an agent-based model (Gilbert 2008) that simulates how industry average profit depends on the ability to select the best suppliers and on agents' cheating attitude. It supposes that there are no problems on the demand side for final producers (FPs) and that their profits and those of the whole industry depend only on the quality of purchases. This model is able to take into account structural and socio-cognitive variables and to show its joint effects. Moreover, it is a path-dependent model, because in each step agents decide not only according to contingent information but also to the knowledge stored in their memory. This way it helps understanding how inter-organizational trust and cheating attitude affect industry profitability. Three types of trust are considered: direct and indirect experience-based and reputation-based. To each one a specific decision-making *process* does correspond and, through a cumulative way, four decision-making *patterns* are simulated: the simplest one is random choice; the second one adds direct experience; the third one adds indirect experience; and finally, the fourth one also considers reputation-based trust. The effects of these four decision-making patterns confront each other in different cheating environments.

The four central topics involved in this work—trust, opportunistic behavior, information availability, and its effects on industry profitability—are prominent in three adjacent fields of study: economics, management studies, and organization science. Mainstream economics focuses mostly on the two latter topics and looks for its optimal structure and on the positive and negative effects of respectively trusting and opportunistic behaviors. Cognitive and evolutionary economics, being freer from the need of finding global or local optima, deserves more attention to agents' micro-behaviors and interaction patterns. Conversely, management and organization studies look mainly at the three former topics mostly (even if not exclusively) from the point of view of single (or networks of) organizations, and particularly focusing on the possibility to employ strategies able to gain advantages from specific combinations

of trust, opportunism and industry structure. This is not the viewpoint taken in this work, though it obviously, hopefully and fruitfully intends to open developments in that directions too. For instance, a further development of this model could address the following issue: if agents behaved in the different ways, would they individually gain some advantage?

Therefore, questions typical of economics, management studies and organization science are inextricably intertwined and mutually feeding. In this sense, as it is actually witnessed by the cross-publications of organization and management scholars and cognitive and evolutionary economists in the same journals, organizations science, management studies, and cognitive and evolutionary economics go side-to-side. Nowadays it is hard to trace precise boundaries between these fields, especially when the interorganizational—which indeed means industrial or territorial—perspective is assumed, like in this paper. Hence, we will refer to empirical and theoretical studies in all these fields, but we will keep the focus on organizational issues. It means that trust is not treated as the result of calculativeness capacity, as it is done in transaction cost economics, reputation is not a component of agents' production functions as in mainstream economics, and agents themselves are not optimizers. On the other hand, the major attention is not put on individuals' strategies but rather on collective behaviors and outcomes, and on scale effects at industry level. Therefore, in the concluding section the implications of our results for organization science will be stressed.

Given a certain structural and socio-cognitive context CIOPS model is able to answer a number of questions among which the following are experimented in this article: what is the effect of cheating attitude on industry profitability? Is there any moderating role of industry size? Which is the most efficient decision-making process?

The article proceeds as follows. In section two, the literature concerning the role of trust, opportunism and reputation within and between organizations is reviewed, and the eventual simulation models developed by some authors are presented. Five groups of hypotheses, which seem to identify the main research questions crossing the whole debate, are advanced. Then the architecture of the model is detailed, focusing on structural and cognitive variables, on decision-making processes and patterns, on the distribution, access, and types of information circulating among agents, and on their learning capabilities and bounded rationality. This section ends by specifying the configurations of virtual experiments, and the main indicators used for interpreting results. These latter are discussed in section four by distinguishing the features at industry and segment level. Finally, before conclusions a fifth section compares our results with those available in empirical and experimental literature and the sixth section discusses the limitations.

2 Background

2.1 Content domain background

It is widely recognized that, especially in developed countries, quality is a crucial competitive factor for industry competitiveness (Mody et al. 2007; Reed et al. 2000). It is also well known that it does not coincide only with product quality (Ashari

Idris and Zairi 2006; Ugboro and Obeng 2000; Williams et al. 2006), but instead it concerns human resource management (Langbert 2000; Matzler and Renzl 2006), services associated with products (Chang 2007), the ability to customize and design goods (Lin and Chang 2006; Lin and Lu 2006), and to coordinate its delivery with customers (Chang 2007; Matzler and Renzl 2006). However, especially in hi-tech industries, product quality plays a decisive role, because they usually imply larger investments, longer delivery time, and hence higher uncertainty. Olhager and Selldin (2004) found that for 128 Swedish manufacturing firms the primary priority for the selection of supply chain partners is quality performance. The key-role of product quality further increases when the clients of hi-tech industries are not the individual consumers of the final market, but instead other firms or eventually knowledge-based institutions, like ministries, research centers, etc. In fact, in these cases clients are well equipped to evaluate the true quality and value of their purchases far beyond what a simple single consumer could do. This is the case of aerospace, biomedicals, packaging machines, etc. (Smith and Tranfield 2005).

Moreover, it is now well recognized that products and environmental complexity tend to fragment production in many segments and many suppliers (Arndt and Kierzkowski 2001). The fast and growing literature on organizational modularity (Garud et al. 2003; Henderson and Clark 1990; Langlois and Robertson 1992; Schilling 2000; Schilling and Steensma 2001), firms changing boundaries (Ashkenas et al. 1995; Colombo 1998; Doz and Hamel 1998), and regional-global industrial and knowledge restructuring and relocation (Biggiero 2006; Gereffi 1999; Gereffi et al. 2005; Humphrey 1995; Humphrey and Schmitz 2002; Sammarra 2005) well witness and discuss this phenomenon.

FPs, that is, downstream firms, are especially solicited to develop managerial capabilities in terms of outsourcing coordination, because production cycles are often horizontally and vertically split. Thus, a key competitive factor for FPs is the ability to find the best suppliers in terms of product quality, which here can mean in a broad sense, as intrinsic product quality, precise delivery, and so on (Chung and Kim 2003). When diffused among many FPs, this ability turns to be a competitive advantage for the whole industry, either because it improves cost management on the supply side or because it allows selling better and thus more competitive products, which are supposed to allow higher profit margins. In fact, though not conclusively and clearly demonstrated by empirical studies, the strong causal relationship between product quality and average profit at industry level is commonly taken for granted (Tyagi 2004).

The economic and organizational literature on trust, opportunism and reputation is enormous. Here we will refer just to essential concepts, starting from those suggested by Williamson and then elaborated and introduced by other scholars. According to transaction cost economics (Williamson 1975, 1985, 1993) outsourcing implies market transactions, which are costly especially when subcontractors are few and its products are complex. Both these factors raise transaction costs respectively, because of opportunistic behaviors and idiosyncrasy. If this latter is kept constant, the crucial variable becomes opportunism and the methods to reduce it. One of these methods is by effectively allocating trust, which would enhance the probability of finding the best suppliers and thus, to increase firms' own product quality, which becomes a key factor of competitiveness. Of course, opportunism does not mean only

cheating, and actually almost all theoretical and empirical studies did consider all the other variables but cheating, as transactions' specificity, frequency or uncertainty, the number of exchanging parties, and eventually their perceived effects on economic outcomes.

However, as Carson et al. (2003) underlie, information-processing abilities allow firms to assess partner trustworthiness better, which reduces the risk of misplaced trust. Using a sample of 129 firms that have engaged outside contractors on client-sponsored R&D projects, they demonstrate that the cognitive dimension is crucial in order to allow a performance improving. Oleinik (2005) asserts that trust is a basic parameter of institutional environment that defines the social acceptability of possible behaviors. Specifically, he distinguishes between institutional trust, which is the reliance in a third party, and a general trust, explicitly how much individuals are willing to trust unknown people. The Oleinik's (2005) perspective points out that the level of trust or distrust in an industry could deeply affect market' rules and firms' behavior.

In a similar perspective Gierl and Bambauer (2002), through an empirical study on 232 German industrial suppliers, argue that information networks can function as a safeguard for dependent suppliers by reducing information asymmetries among the networking parties and by developing group norms.

According to Coleman (1990), trust is an on/off condition, in the sense that it is supposed that, if one trusts the other, the one who trusts does not accurately evaluate the possibility of cheating—which is eventually also because of convenience. Conversely, what Coleman calls distrust, indicates the reluctance to commit without guarantee. In this sense, it is a quite radical and dichotomic position, because in concrete practices many mechanisms of graduation can be conceived and discovered. They could called as forms of "prudent trust", and range from various types of backward and forward learning processes to institutional or social isomorphism (Zucker 1986).

These arguments lead to focus attention on information exchange among firms, and consequently on its reliability. If those studies demonstrated that without information exchange the trust effect can be vanished or considerably reduced, our work aims at investigating the role played by information credibility. The central idea is that if information is false its exchange does not help profitability. In this sense, opportunism is here defined as agents' propensity to lie and not as their possibility to shift from a supplier to another one, as it is usually done in empirical research (De Jong and Nooteboom 2000; Gierl and Bambauer 2002; Humphrey 1998; Nooteboom 2002; Sako 1998) and in theoretical analysis (Gambetta 1988; Kramer and Tyler 1996; Lane 1995; Sydow 1998).

In line with the perspectives of cognitive approaches to organization theory (Lant and Shapira 2001; Tenbrunsel et al. 1996) and cognitive economics (Egidi and Rizzello 2003; Kahneman 1996; Novarese 2003; Rizzello 2003), the definition of opportunism as cheating attitude represents an element of originality of our contribution, because cheating behaviors, which usually are not related to agents' opportunistic strategies in the meaning attributed by economics and organization theory, are instead investigated within the fields of cognitive science and social psychology. Of course, it will be very interesting, in future developments of this or other models, to

keep both aspects of opportunism at once, that is, implementing and leaving playing both cheating attitudes and previous agreements' defaulting.

The relevance given to this matter by management studies and economics is well witnessed by the extant literature on the ways to create, analyze, maintain, and improve trust within and between organizations (Bachmann and Zaheer 2006; Kramer and Tyler 1996; Lane and Bachmann 1998). Among the many dimensions and types of trust extensively reviewed by Lane (1998) and Nooteboom (2002, 2006), three types can be individuated because particularly salient for inter-firm relationships (Hardy et al. 1998; Lane 1998; McEvily and Zaheer 2006; Sydow 1998): calculativeness-based, identification-based, and reputation-based. The relevance of calculativeness-based trust is usually emphasized by those economists (Williamson 1993), who tend to neglect socio-cognitive and social-psychological aspects or to squeeze them on masked forms of calculativeness. Conversely, other economists (Egidi and Rizzello 2003; Holland 1996; Kahneman 1996; Novarese 2003; Rizzello 2003; Tversky 1996) put these aspects at the core of their studies. They start from behavioral economics to precisely define, operationalize, and analyze the many issues related to the various forms of bounded rationality. In this domain it can be included also knowledge-based trust, which refers to direct and indirect experience that occurs between transactors, and revolves on the idea that agents' behavior do not change so quickly, especially when occurring between the same actors. In fact, calculativeness- and knowledge-based trust are based on and produce knowledge. They are both explicitly implemented in our model in the form respectively of decision making algorithms and of information agents collect from their own and others' experience. These latter can be seen as internal and external knowledge sources (Biggiero 2009a).

This same goal is shared by some scholars of organization theory (Burt 2001; Carley 1986; Guastello 1995; Lin and Li 2003; Nooteboom 2002; Prietula 2001), who, being free from the theoretical constraints of mainstream economics, have more deeply developed concepts and models of organizational behaviors at group, organizational, and interorganizational levels. Trust attracted a special attention in recent literature (Bachmann and Zaheer 2006; Gambetta 1988; Kramer and Tyler 1996; Lane and Bachmann 1998), and in particular it is considered a crucial factor of competitiveness in supplier-buyer relationships (De Jong and Nooteboom 2000; Humphrey 1998; Lane 1995; Lane and Bachmann 1996; Sako 1998; Tan 2001) and in strategic alliances (Child 1998).

Identification-based trust concerns a very special form, because, being related to symbolic or to issues somewhat external (and partially independent) to single agents, it is depersonalized. In fact, according to social identity theory (Turner, 1982, 1984, 1985; Turner et al. 1987) and organizational identification (Ashforth and Mael, 1989, 1996), provided by the reciprocal recognition to share the same values and identity, people can trust each other without any direct (personal) interaction. This perspective has been applied to industrial districts (Sammarra and Biggiero 2001) and to strategic groups (Peteraf and Shanley 1997), thus arguing that this phenomenon, which was traditionally studied in reference to social relationships between individuals and groups (Tajfel, 1978, 1981; Tajfel and Turner 1979), holds also between firms. However, though theoretically pertinent to our theme, this type of trust has not be implemented in this model.

According to Barnett et al. (2006) corporate reputation is made by "observers' collective judgments of a corporation based on assessments of the financial, social, and environmental impacts attributed to the corporation over time" (p. 34). Consequently, reputation-based trust associated to firms refers to collective opinions that have been formed and are recognized by single agents through direct or indirect experience. In current literature corporate reputation is considered one of the most important intangible assets and a crucial variable to ensure good economic performance (Hall 1992; Horner 2002). It is generally agreed that a good reputed company attracts new clients, has a good rating from finance actors, is able to easily overcome crisis events, and it is considered a good partner for alliances (Martinez and Norman 2004). Although researchers do highlight the role of corporate reputation for economic performance, at the moment there is no uniform view on its definition and measurement (Martinez and Norman 2004).

Recent debate distinguishes image and reputation (Fombrun and Van Riel 1997). Grunig (1993) and Williams and Moffitt (1997) affirm that image is the instant impression an evaluator acquires of a given firm, whereas reputation is based on perceptions obtained in previous interactions and it emerges slowly as a whole evaluation. Similarly, Cornelissen and Thorpe (2002) argue that images become manifest from the interaction among the evaluated agents' behavior and the evaluator's perception at a given time. In contrast, they suggest that reputation is a collective and summarizing representation of old images acquired either from direct experience or from communication (Cornelissen and Thorpe 2002). Hence, whereas images change over time, reputation has a more inertial and constant trend, because stakeholders tend to preserve positive organization evaluations obtained over time (Wartick 1992; Cramer and Ruefli 1994; Fombrun and Van Riel 1997). Similarly, Fombrun (2006) considers reputation as the aggregated and whole evaluation shared by a firm's stakeholders.

CIOPS model adheres to this approach and implements reputation as resulting from a given number of convergent images. As stated in Sect. 3.4, reputation emerges when an agent acknowledges that an organization is perceived in a coherent manner by a given critical mass of other agents. Moreover, because an organization may be evaluated in a different manner by different agents, different reputations on the same agent may be formed. Thus, in this model, reputation is not necessarily a global evaluation, but it could emerge as a local evaluation shared by a small group of agents: "reputation is perceived not just at the aggregate level but also among groups of similarly situated stakeholders" (Martinez and Norman 2004, p. 26).

The CIOPS model allows us to join the debate here summarized and to understand the effects of cheating, trust and reputation on industry profitability. In fact, this model considers different decision-making processes based on three forms of trust: direct experience, indirect experience and reputation-based trust. By testing five groups of research hypotheses, the CIOPS model focuses the main issues previously addresses reviewing current literature. The first one concerns whether there are differences in agents' capability to reach industry maximum profit into the medium-long run (that is, in a stable regime) depending on their attitude to cheating. This is clearly the main issue at the ground of all researches in economics, management and organization theory directed to understand the consequences of opportunistic behaviors. If they were irrelevant for competitive advantages or for reaching profitability,

then likely they would be much less interesting for these scientific fields. Indeed, the whole theoretical framework of transaction cost economics and of its developments in management and organization theory are based, and the related empirical studies are directed to understand if and to what extent opportunistic behaviors damage or facilitate profitability at industry and/or firm level. As we said before, in this paper only the former is investigated by formulating the following:

Hypothesis 1a: in the medium-long run (that is, in a stable regime) honest agents bring industry profitability to its maximum.
Hypothesis 1b: in the medium-long run, dishonest agents are not able to bring industry profitability to its maximum.
Hypothesis 1c: there are differences depending on agents' decision-making patterns.
Hypothesis 1d: there are differences depending on agents' attitude to cheat.

The second group of hypotheses addresses to the issue of the effects induced by industry size. It should be expected that with larger number of agents it becomes more difficult to reach maximum profitability, because it is harder to find the best suppliers. Moreover, direct experience should count less, because each agent has a limited possibility to explore the whole decision space. Consequently, since they are forced to use more extensively indirect experience, when agents are dishonest the damage of opportunistic behavior to industry profitability is expected to be much more remarkable. Hence, we can suggest the following:

Hypothesis 2a: ceteris paribus, in larger industry size there is a lack of profitability.
Hypothesis 2b: ceteris paribus, in larger industry size the lack of profitability increases dramatically if agents are dishonest.
Hypothesis 2c: direct experience counts much less in larger industries.

Since the CIOPS model distinguishes the contexts of half and full cheaters, it is possible to raise hypotheses concerning the effects of (uniform) cheating attitudes. The damage to industry profitability provoked by opportunism is of course expected to be much higher in the case of full than in the case of half cheating, but, due to the presence of nonlinear mechanisms, the loss of profitability could be not proportional. If this hypothesis were confirmed, the interesting implication is that a substantial weakening of social trust between firms could damage industry profitability almost as if nobody trusted each other at all. Hence, it would imply that trust is a very sensitive variable for industry competitiveness. Moreover, this phenomenon is expected to play more heavily in larger industry size, that is when the information space is too large to be effectively explored by single agents. These hypotheses can be stated as follows:

Hypothesis 3a: the damage in terms of lack of industry profitability provoked by opportunism is not proportional to the cheating attitude;
Hypothesis 3b: the damage in terms of lack of industry profitability provoked by opportunism is much higher between zero and half-cheating than between half and full cheating.
Hypothesis 3c: the non-proportionality of the effects of cheating attitude is higher in large than in small size industries.

The fourth group of hypotheses regards dynamic aspects by wondering which decision making pattern and which behavior allows to fast reach maximum profitability

and maintains more stable into the medium-long run. This question is indeed quite crucial because, especially in those hi-tech industries characterized by high environmental complexity or innovation uncertainty, the short run is the most relevant one. Hence, it becomes fundamental to understand not only to what extent in the long run industry profitability reaches its maximum, but also under which conditions it is reached at fastest. Now, given the agents' cognitive boundaries, it should be expected that without opportunistic behaviors the decision making patterns exploiting indirect experience give a superior performance, and that this advantage increases with enlarged industry size, because agents' own cognitive limits grow and count more than proportionally. However, if agents cheat the superiority of indirect experience is reduced by the damages produced by false information, and thus, the speed to maximum or highest performance should be decreased accordingly. Therefore, we can raise the following:

Hypothesis 4a: without opportunistic behaviors the decision-making patterns exploiting indirect experience give a superior performance in terms of speed to reach a stable performance.

Hypothesis 4b: if agents cheat, the superiority of indirect experience in terms of speed to reach a stable performance is reduced.

Hypothesis 4c: in presence of large industry size, the advantages of decision-making patterns exploiting indirect experience in terms of speed to reach a stable performance are stronger.

The fifth group of hypotheses focuses the eventual differences between the two segments of final producers and first tiers. The two segments of final and intermediate products are constituted by the same types of agents, and even by the same selection and behavioral rules, decision-making patterns and cognitive capacity and boundaries. However, there are two differences. The first one refers to the place where the selection process starts up: from downstream (final producers) to selecting and proposing orders to intermediate firms. Consequently, it could happen that, when the selection of the best suppliers is more difficult, the performance of the two segments will differ, likely disadvantaging the intermediate agents.

The second difference is represented by the number of agents in the two segments, because first tiers are double of final producers. However, occurring a one-to-one trade relationship, only half first tiers are activated in each step. The same mechanism holds between activated first tiers and potential second tiers, that is between the agents operating into the upstream segment of raw materials. If the selection process were harder with dishonest agents and/or in larger industry size, then it is reasonable to raise the following:

Hypothesis 5a: with opportunistic agents, the collective performance of intermediate agents differs from that of final producers, and likely advantaging these latter.

Hypothesis 5b: in large industry size the collective performance of intermediate agents differs from that of final producers, and likely advantaging these latter.

Hypothesis 5c: with opportunistic agents and in large industry size the collective performance of intermediate agents differs from that of final producers,

and likely advantaging these latter and with a major gap respect to the case of only one of the two factors.

Before going deeper inside the methods background, the model structure and the specific configurations of the virtual experiments, it should be highlighted that all the previous hypotheses will be tested under some major and minor assumptions, which will be discussed in detail in next sections. Five of the majors are quite strong and, since of course they limit the possibility to generalize our results, it is better to anticipate them hereafter: i) agents are all equal in terms of size, cognitive capacity and boundaries, and selection devices (decision making patterns and processes); ii) agents' behavior is invariant, which means that they do not perform elaborated strategies but only repeat the same behavior among alternative decision making processes just led by feedback mechanisms. In other words, beyond choosing the best decision making process they do not activate special strategies, like retaliation or sophisticated learning processes; iii) their memory, and thus their knowledge growth, is undermined by four forms of forgetfulness; iv) the sole form of product differentiation is between industry segments, that is between raw materials, intermediate goods, and final products. Implicitly, this represents also the only form of agents' differentiation; v) there is no firms' turn over, and therefore failed or inadequately profitable firms do not exit and new ones do not entry. The implications of these major assumptions for the current scientific debate and for the future research developments will be discussed into the last two sections (limitations and conclusions).

2.2 Methods background

A common approach of organizational scholars and evolutionary economists is the idea that static theories and models do not help very much, because real organizations and industries are dynamic and nonlinear, and thus, its behavior cannot be studied with traditional approaches. Most relevant phenomena do emerge out of a huge number of individuals' multi-dimensional interactions. Equilibrium conditions are no more a theoretical constraint, and multiple stable states are eventually admitted. Moreover, organizations are not reduced to production functions and individuals to utility functions. Consistently with this perspective, CIOPS model is dynamic and nonlinear, and it enables to analyze if, how, and when dynamic patterns lead to stable regimes.

Agent-based modeling is an extraordinary tool to build and test theories in social sciences, because it allows as much complexity as the designer is able to implement and as the theorist is able to interpret in terms of results. Moreover, for testing theories, they are an excellent method to work out the well-known difficulties of comparing and controlling results. In the specific field of industry modeling the major attention has been devoted mostly, though not exclusively (Brenner 2004; Merlone and Terna 2007; Merlone et al. 2008; Squazzoni and Boero 2002; Tesfatsion and Judd 2006; Zhang 2003), in applying Kauffman's (1993) approach of fitness landscape (Chang and Harrington 1997, 2000, 2003, 2004, 2006; Frenken 2006; Kauffman et al. 2000). Actually, it breaks some of the chains of neoclassical economics and general economic equilibrium (Arthur 2006; Chang and Harrington 2006;

Tesfatsion and Judd 2006), but it is still too poor for being really appealing, because agents and their interaction mechanisms are extremely simple.

Even if some organizational scholar followed this reasoning (Carroll and Burton 2000; Levinthal 1997; Levinthal and Warglien 1999; Levitan et al. 2003; Rivkin and Siggelkow 2003; Yuan and McKelvey 2004), some others took different directions (Ashworth and Carley 2007; Davis et al. 2007; Dooley 2002; Lomi and Larsen 2001; Lomi and Pattison 2004). In this latter perspective, Carley's work in bridging organization science with artificial intelligence (Carley and Gasser 1999; Carley and Newell 1994) and cognitive science (Epstein 2005; Gilbert and Troitzsch 2005; Sun 2005) has been fundamental (Carley 1986, 1989, 1995, 2002; Carley and Hill 2001; Carley and Prietula 1994; Prietula et al. 1998). The models developed in this perspective are characterized by cognitively richer agents and more complex and realistic interaction mechanisms than those based on fitness landscape approaches.

Until few years ago, the major part of modeling approaches to trust and reputation followed a game theoretic perspective. The principal aim was that to find the minimum conditions sufficient to generate cooperative behaviors. Conversely, this paper and the CIOPS model have quite different premises and goals. The premises are rooted into the economic and organizational literature on trust and opportunism within inter-organizational relationships. The goals are those of understanding the role played by trust and opportunism in the evolution of such relationships. This modeling approach is not far from those recently developing in sociology (Bowles et al. 2003; Conte et al. 2001; Epstein 2001, 2005; Epstein and Axtell 1996; Hodgson and Knudsen 2004) and in cognitive science (Castelfranchi et al. 1998; Conte and Paolucci 2002).

In particular, through computer simulation, Burt (2001), Prietula (2001), Klos and Nooteboom (2001), Lin and Li (2003), Tychonov et al. (2008), and Giardini et al. (2008) elaborated on the specific issues of trust and reputation, which are crucial themes of this article. However, among these scholars, only Klos and Nooteboom (2001), Giardini et al. (2008) and Tychonov et al. (2008) deal with agents representing firms interacting at industry level, whereas the others modeled these phenomena at individual or organizational level.

Burt distinguishes three ways to measure trust depending on the relative positions of actors within their networks. The first way, that he calls baseline, is the most traditional one, and refers to the strength of direct relationships. The other two concern the bandwidth and the echo effects. Bandwidth occurs when, especially in relatively closed networks, egos tend to maintain uniform opinions with alters. This is precisely related to the mechanisms of reputation formation, change, and diffusion. The echo hypothesis refers to the social-psychological mechanism that prevents or hinders a gossiper to disclose his bad judgment about alters to somebody who is perceived having good judgment of such alters. Though not immediately testable in this version, all these three ways of trust formation and circulation can be dealt with CIOPS model. Respect to what is suggested by Burt, in this model reputation diffusion is limited to the outcomes of direct experience-based trust.

Following Carley and Newell's (1994) model of social agent, Prietula (2001) examines how trust affects workgroup performance. Members are boundedly rational in computational terms, and exchange information in real-time in a social setting where

multiple agents exist. Agents work in a group where they have to pursue some tasks, which require a certain amount of information. If they do not succeed in reciprocal interactions, they are sanctioned by getting less knowledge, and consequently lowering their performance. Both these characteristics are common with this model, which also follows the perspective of cognitive social agent, who employs his knowledge to improve selection of quality suppliers. To the extent a single agent finds the best suppliers, he gains more profit, and increases its average profitability.

Lin and Li (2003) study how competency-based individual-level trust affects organizational performance through micro-macro processes. Following the same socio-cognitive computational approach adopted by Prietula and by the authors of this article, and refining a previous study (Carley and Lin 1997), their contribution has the further merit of treating interpersonal trust as hierarchical, and not as symmetrical and lateral as in prior research. Agents should work out problems in various uncertain tasks environments. Trust from a member to each of his subordinates is based on how well the subordinate has provided decision information in past direct experience between the two. This in turn determines how much subordinates' current information counts in the superiors' decision making (Lin and Li 2003).

Through an agent-based computational model Klos and Nooteboom (2001) study how cooperation and trust emerge and shift adaptively as relations evolve in a context of multiple, interacting agents. They make and break transaction relations on the basis of preferences, trust and potential profit, which is a function of product differentiation, specificity of assets, economy of scale and learning by doing in ongoing relations. According to the notion of trust as the subjective probability that a potential gain will be realized (Gambetta 1988), in this model trust is adaptive and a function of partners' loyalty, as exhibited by their past lack of defection to more attractive alternatives. In line with transaction cost theory opportunism consists of the attitude to betray past contracts to better exploiting present alternatives. In order to maximize their profits, agents change trust attitude depending on the specific context in terms of product differentiation, scale economies, and preferences. This model has been further developed by Gorobets and Noteboom (2004).

Based on Conte and Paolucci's (2002) theoretical approach, Giardini et al. (2008) developed a model to study reputation dynamics in industrial districts. Its architecture and functioning is very similar to CIOPS model, because agents search for the best quality suppliers, the industry is structured into three segments, and under many other respects. Thus, the two models are highly comparable.

Through an agent-based simulation of the trust and tracing game (Meijer and Verwaart 2005), Tychonov et al. (2008) model human behavior in food supply chains with asymmetric information about food quality and safety. Buyers and sellers negotiate trade agreements according to the kind, quality and price of products, and some additional guarantee conditions. The buyers' utility function is a weighted sum of normalized functions of price, satisfaction difference between high and low quality (for consumers) or expected turnover (for others), and risk, while the sellers' utility function is the weighted sum (linear combination) of normalized functions of effective price and sellers' risk. "Tracing reveals the real quality of a commodity. The tracing agent executed the tracing and punishes cheaters as well as traders reselling bad commodities in good faith" (p. 11). Moreover, besides the role of tracing agents,

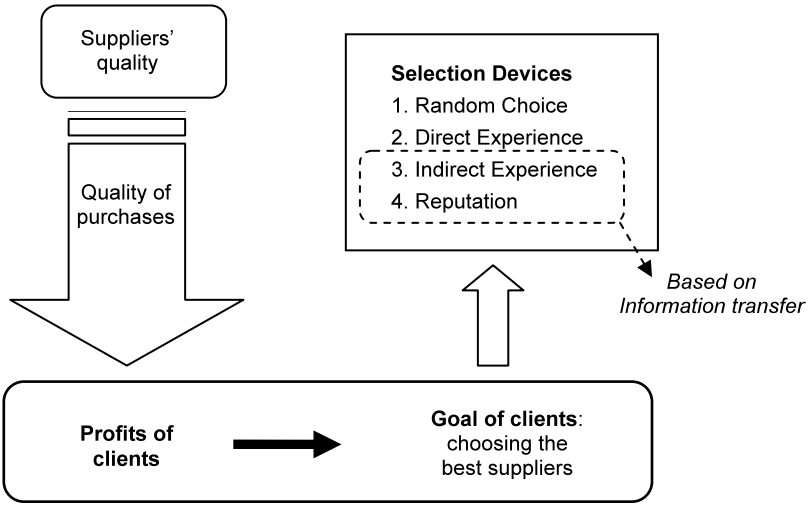

Fig. 1 The general structure of the model

Tychonov's et al. (2008) model is enriched also by the role played by sellers' stock and trade negotiations. Cheating is an implicit characteristic of opportunism in the sense that who behaves opportunistically implicitly cheats regarding the true product quality. Conversely, in our model cheating realizes opportunism in the pure sense of that word, that is by giving false information. However, in both models cheating refers respectively to sellers' and suppliers' product quality.

3 CIOPS architecture

The model is articulated in two classes of variables: structural and cognitive ones. To the former belong economic and technological variables, such as cost structure, production cycle, and industry size. Cognitive variables deal with: i) the type and quantity of information circulating within the industry; ii) agents' cognitive abilities and levels of aspiration; iii) agents' decision-making processes. After discussing these variables, this section ends with a summary of the virtual experiment configurations and performance parameters.

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. Because final producers do not 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 firms, who play the role of reciprocal informers. Agents are trustworthy or are variably opportunistic, and this latter behavior is because of a certain propensity to cheat. This represent the main threat to the individuation of the best suppliers, and consequently to the achievement of high profits.

3.1 Structural variables

A final product requires more than one phase of production, each one composed by a set of specialized firms connected in a sequential technology: final producers (FP) get their intermediate products from first tiers (FT), that is, intermediate firms that in turn are supplied by second tiers. Production orders flow obviously in the opposite direction. Thus, it is possible to identify three segments: downstream, intermediate, and upstream. Consequently, orders and goods are exchanged within two markets: a market among final producers and first tiers, and another among first tiers and second tiers. Orders start from external market, which is supposed to demand at each simulation step one product per each final producer. Therefore, each FP orders components to one intermediate supplier, who in turn orders its products to one upstream supplier of row material. A one-to-one relationship holds between suppliers and clients, that is, in each step and in each market a client orders products to just one supplier, and vice versa.

Suppliers are selected according to their quality. However, actual suppliers' quality is verified only after transactions, because either clients could not know it in advance or they could have incorrect information. Actual suppliers' selection depends on clients' experience and cognition: knowledge, computational capacity, expectations, information reliability, and decision-making processes. All these issues are discussed in next three subsections.

Firms' individual performance depends on sales price, which depends on suppliers' quality, and it is not bounded on the higher side. Conversely, clients' purchases costs are fixed, so that their profits directly depend on suppliers' quality. Sales are calculated according to the expression:

$$S = 1.2Q_s.$$

Where $S =$ sales value and $Q_s =$ quality of supplier's. Assuming a quality between 1 and 0.5, sales are maximum (1.2 million euro) when quality is 1 and they lower proportionally to the decrease of quality. Clients buy from suppliers at the fixed cost C, consequently, clients' profits are given by:

$$P = S - C = 1.2Q_s - C.$$

By putting $C = 0.75$ million euro, firms reach 450.000 euro profit when quality is 1 and -150.000 euro when quality is 0.5. FT has the same cost-profit structure, so that average and agent's quality is transferred from one to other segments only through its effects on agents' profits. Moreover, a ratio of $2/1$ is supposed between suppliers in each segment and FP, so that they always find some supplier.

3.2 Cognitive variables

Each agent has individual representation of the structural network, that is, of who produces what, and with what quality. Thus, each agent has an individual specific cognition of each other and it is perceived in a potentially different way by each other. Figure 2 shows this approach by distinguishing a structural network composed

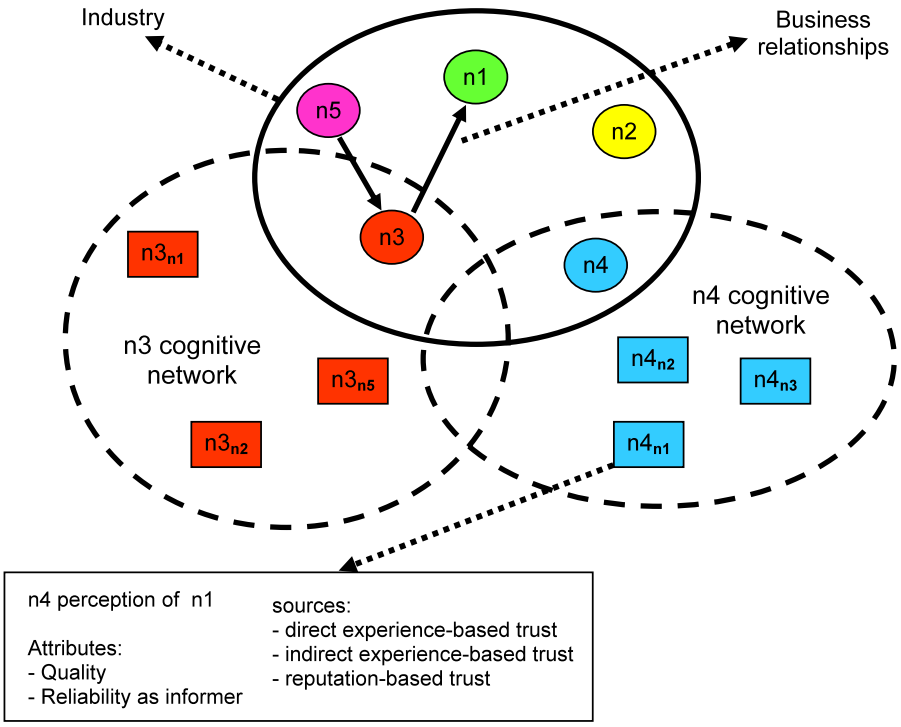

Fig. 2 Interactions between the structural and the cognitive networks

by firms ($n1, n2, n3 \ldots$), and a cognitive network per each firm, which constitutes its own representation of other agents. For example, $n4_{n1}$ represents how $n4$ perceives (and evaluates) $n1$. It is worth noting that cognitive networks may have missing data (in Fig. 2 $n4$ has no information on $n5$). To belong to the cognitive network of a certain single agent, it is necessary that that firm is acknowledged.

Information differs according to the following three types of source:

- direct experience-based trust (DEBT), which comes from previous direct experience;
- indirect experience-based trust (INDEBT), which arrives from a third element, the informer, who has had direct experience;
- reputation-based trust (REBT), which is formed when many informers' opinions do converge.

Notice that the three types of trust are completely independent and unevenly distributed among industry. For instance, a certain agent can be known only in terms of DEBT, whereas another only in terms of REBT. Moreover, different sources can give contrasting indications, that is, the same agent can be evaluated in very different ways by different informers either in terms of the same or different types of trust. Finally, during the virtual experiment, individual cognitive networks do change in number of nodes and attributes.

3.3 Decision-making patterns

As firms' performance directly depends on suppliers' quality, they have to manage and use their cognitive networks to find out the highest quality suppliers. This model is implemented with four types of decision-making patterns based on different information sources of trust:

a) RND: random choices;
b) Led by DEBT: choices are based only on direct experience. Among available suppliers, clients choose the ones that gave the highest quality in past direct transactions. If nobody of them records the minimum average expected quality, then the supplier is chosen randomly;
c) Led by INDEBT: choices are also based on indirect experience. Looking for information, clients become questioners, who ask informers about the expected quality of available suppliers. Per each choice a questioner can ask an informer just once, and thus, to get more information, the questioner should ask more informers. This decision-making process requires the activation of another decision-making process, now addressed to evaluate informers' reliability, which in this version of the model is intended without any graduation. By scanning all information cumulated in his own life, the questioner chooses the supplier with the highest quality score. However, before reaching the final decision, the quality of the supplier selected in this way is confronted with that coming from the DEBT decision-making process. The best quality supplier among the two will finally be chosen. If none of the DEBT or INDEBT based decision-making processes will give any supplier with a sufficient average expected quality, then choice will be made randomly. Thus, when INDEBT is activated, agents trust information based on direct and indirect experience;
d) Led by REBT: clients consider also suppliers' reputation, and in case there were more than one with a reputation, then they choose the best one. Even in this case, results deriving from this decision-making process will be compared with those coming from INDEBT and DEBT, and the supplier with the best reputation is chosen. Again, if no satisfying result is got with these choice strategies, then the supplier is chosen randomly. Thus, agents using REBT decision making rely on information from direct and indirect experience, and reputation with the same confidence.

Figure 3 shows the flow chart of REBT decision-making pattern. To focus only on the INDEBT flow chart it is enough to deactivate the command "Extract the best available REBT", while the DEBT decision making pattern needs to inactivate also the "Extract the best available INDEBT" command.

3.4 Distribution, access, and types of information

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.

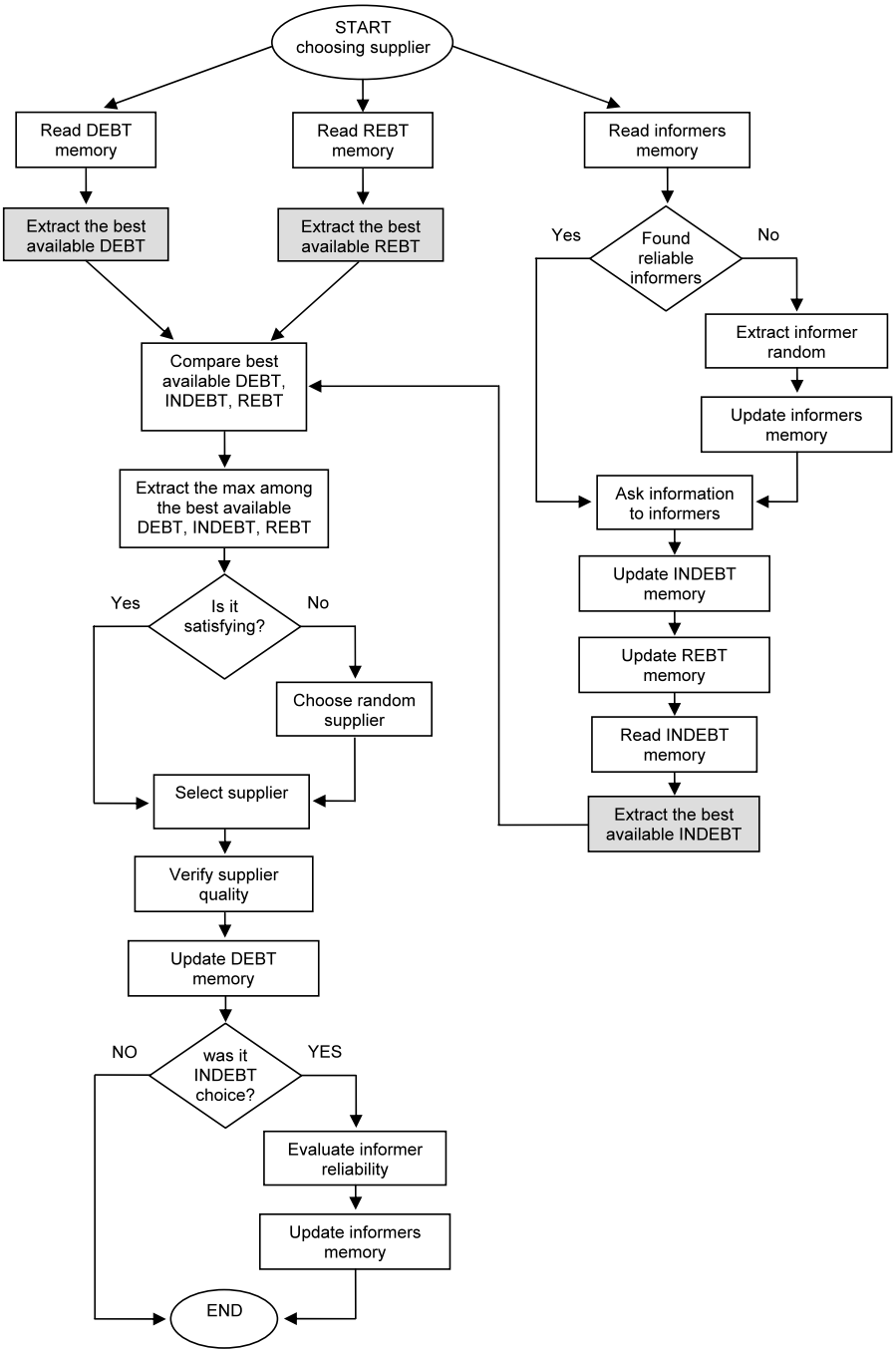

Fig. 3 Flow chart of REBT decision-making pattern

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 smaller than the number of questions that the questioner is able to ask, then the questioner also asks some unknown randomly chosen informer. The number of questions that the questioner is able to ask is part of its computational capability, which is fixed at four informers uniformly for all firms, and kept constant during the whole virtual experiment.

Informers' trustworthiness depends on the truth of information that that informer passed previously to a 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 to 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 by reputation. False informers indicate the worst supplier as if it were their best. That is, cheaters say that the worst supplier has the best quality. There is no answer when informers have none of the two sources of information.

Because in this model agents have been supposed not to change behavior, then, in terms of Coleman's approach, they are in a middle position between trust and distrust. In fact, they have the certainty that who cheated will continue to do so even in future, whereas toward others a behavior of "prudent trust" is maintained. Following an informer's suggestion, and before engaging the indicated supplier, the questioner checks whether there is more information about that supplier. If the informer is already known, the questioner knows whether he is reliable or not, but if the informer is not known there are no specific evaluations on informers expediency to cheat. This is one of the many forms of learning processes that can be implemented to escape from a dichotomic view of trust. Specifically, it is a "light" and backward form, because it does not imply complex cognitive resources and it looks only at the past.

Agents have an inclination toward cheating, as the probability that, in each interval, false information is given, and it is kept constant during the virtual experiment. If the attitude is zero, then agents always pass true information. When it is 0.50, it means that in each interval agents have a 0.50 likelihood of cheating, and finally when it is 1, they always cheat. It is crucial to underline that in this model 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 do not, 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 acknowledgment 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, even as the origin of reputation is based on informers' answers convergence, subsequently it could be quickly passed to other agents through communication processes. This is the only form of gossip working in this model, because informers do not take the responsibility of the reputation passed to clients.

As informers can communicate false information, in this model at the same time different evaluations of the same supplier could coexist. Consequently, at the same time a given supplier can be assigned a different reputation according to the questioner. In other words, an agent may have different reputations in different cognitive networks. Moreover, because of questioner's new indirect experiences or informers' new reputation acknowledgments, a given supplier's reputation can change over time. This is what is meant when it is argued that in this model, in each step, there are as many cognitive networks as there are agents, and over time much more are created and evaluated.

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, whereas reputation-based trust can derive either from informers who signal it as reputation or from converging indirect experiences. Through searching routines, agents collect a set of information, which are stored in their cognitive network to build and update DEBT, INDEBT, and REBT values. However, a certain forgetfulness effect has been implemented, which concerns information inactivated for long time. After a given number of intervals, agents lose information about suppliers or informers. Therefore, there are four types of forgetfulness: one for each decision-making process, plus one for informers. The number of intervals triggering forgetfulness is fixed during the virtual experiment, but it produces its effects in an agent-specific way. After 100 intervals of inactivated direct experience, 40 steps of inactivated indirect experience, and 60 of reputation, the corresponding information dissolves. Similarly, informers who were not consulted for more than 60 steps disappear from questioners' memory.

3.5 What do agents do?

The agents in this model are all equal in cognitive terms and in 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 tiers are randomly assigned a given quality, and certain initial opportunities are randomly offered to FPs and FTs.

According to Carley and Newell (1994), cognitive agents are characterized by a certain computational (bounded) capacity, a unique main goal, a set of expectations,

a (bounded) ability to recognize other agents, to cumulate knowledge, and treat information. Consistently with this view, the agents in this model possess a repertoire of capabilities, which, though far from being strongly rational, in most circumstances allow them to improve their choices to select the best suppliers combining four types of decision-making processes.

CIOPS model assumes uniformity of agents' computational capacity, that is, of their calculativeness, and therefore that form of trust is not an element for exploring results, though obviously it is a relevant parameter. Knowledge-based trust is fully recognized and split into this model in two distinct forms: direct and indirect experience. Identification-based trust is not considered, whereas reputation-based trust is developed and well articulated.

Agents have four types of memories (knowledge): direct experience, indirect experience and reputation, and informers' (un)reliability. Agents differ on which type, how much, and how reliable their knowledge is. Knowledge at industry level is just the sum of agents' knowledge, but not all knowledge is circulated (passed). 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, through 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.

By building and managing several types of knowledge and by confronting it with current information, agents are allowed to learn not only how to improve suppliers' selection, but also to learn what the best decision-making process is and who the unreliable informers are. Specifically, agents learn by constantly confronting their current information with what they already know. Thus, agents' learning is always contingent, because it is not fixed into a specific state, but instead left to a sort of continuous recalculation confronting current and stored knowledge. Agents do not "draw general findings" from their existing knowledge, but just use it for seeking their goals moment-by-moment.

Noticeably, agents also build their own picture of what informers know. In other words, through inquiries agent i builds a picture of what and whom agent j knows. Remarkably, by merging information contained into the memory related to each informer with one's own memory, each agent is able, to some extent, to individuate others' cognitive networks and memory.[1] Therefore, the representation of reality takes the form of a set of information concerning suppliers' quality, informers' reliability, and the corresponding cognitive networks.

As concerning trust and opportunistic behaviors, though agents' "prudent trust" does not activate pure forms of retaliation, it determines a kind of passive (or weak) retaliation that prevents to replicate the mistakes due to trust misallocation. Once an informer has been recognized as unreliable, the questioner cancels 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.

[1] Notice that this process is disturbed by the various types of forgetfulness effects.

Moreover, it should be noticed that the agents in this model acquire free information, because it has no price and informers cannot refuse to give it. Moreover, agents are provided with a good level of computational capacity. In fact, in each choice-interval they: 1) choose four informers; 2) ask each of them four questions; 3) compare answers with their memory; 4) make the decision; 5) mark the outcome of the decision as good or bad; and 6) store all new information in their memory. As it can be seen, this is a lot of cognitive work, much beyond what usually small enterprises do in the real business life. 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, the "prudent trust" characterizing these agents has an indirect cost that affects performance: at least in consequence of the first lie received from a cheating informer, the questioner could be addressed to a bad supplier, and thus, his own performance is damaged. Being simply the sum of individual agents, industry profitability is negatively affected. In this model, reputation-based trust is more "insidious" and dangerous, because, as it does not imply informers' responsibility, the recognition of its eventual falsity does not lead to the rejection of the informer who passed it. Therefore, that informer can again do damage to that questioner. Indeed, this is the essence of gossip.

3.6 Configurations of virtual experiments

In present virtual experiments,[2] the parameters and initial conditions considered are shown in Table 1. In each step, a whole cycle choice/order/production/payment takes place. Supposing that it can represent a reality in which it lasts five working days, 400 steps describe 10 years of industry evolution from the very beginning.

Experiments are executed varying industry size (with 50, 200, and 2000 firms), tendency to cheat, and decision-making pattern, even as keeping other parameters constant. Virtual experiments are labeled as follows:

- RND: industry where only random decision-making process is activated;
- DEBT: industry where DEBT is added to random-decision making process;
- INDEBT0: industry where INDEBT decision-making process is added to DEBT, and agents do not cheat;
- INDEBT.5: industry where INDEBT decision-making process is added to DEBT, and agents cheat with a 0.5 inclination;
- INDEBT1: industry where INDEBT decision-making process is added to DEBT, and agents always cheat;
- REBT0: industry where REBT decision-making process is added to INDEBT and DEBT, and agents do not cheat;

[2]The program running the model is 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), available at www.business.auc.dk/lsd. Authors are available to give any support to use it.

Table 1 Virtual experiments parameters

Structural parameters with constant values	
Production cycle (vertical segments of the industry)	3: downstream, intermediate, and upstream
Quality	Randomly uniform distribution between 0.5 and 1
Cost structure (in thousands of euros)	$P = 1200Q_s - 750$
Cognitive parameters with constant and uniform values	
Number of questions	4
Quality threshold	0.75
Firms' reliability threshold of informers	1
Firms' reliability of unknown informers	1
Number of convergent information to form reputation	4
Range for convergent information	0.1
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	
Industry size	50 firms: 10 downstream firms, 20 suppliers into the intermediate segment and 20 suppliers into the upstream segment. 200 firms: 40 downstream firms, 80 suppliers into the intermediate segment and 80 suppliers into the upstream segment. 2000 firms: 400 downstream firms, 800 suppliers into the intermediate segment and 800 suppliers into the upstream segment.
Varied but uniform (among agents) cognitive parameters	
Decision-making processes/patterns	RND, DEBT, INDEBT, REBT
Inclination to cheat	0, 0.5, 1

- REBT.5: industry where REBT decision-making process is added to INDEBT and DEBT, and agents cheat with a 0.5 inclination;
- REBT1: industry where REBT decision-making process is added to INDEBT and DEBT, and agents always cheat.

Because of the high number of variables and the value that each variable may assume for each agent, it is assumed that within each virtual experiment firms differ only in quality even as keeping constant other parameters. For example, they have

the same quality threshold, refer to the same decision-making process, and have the same inclination to cheat.

Additional analyses to examine the sensitivity of virtual experiment findings have been conducted by varying the number of intervals to forget inactivated knowledge and the tendency to cheat. Sensitivity analysis confirmed the robustness of the main findings of this study. The authors also tested the impact of the built-in randomness of the model by running the same parameter configurations with 10 different random number generators. These experiments showed very little differences in dynamic patterns, which reached the stable regimes at the same time and with similar values of indexes. The effects of more extended virtual experiments have also been tested. They showed that in three times longer runs, performances of the four decision-making patterns maintain their stable regime. As duration of virtual experiments neither changes the qualitative effects of the model nor adds much knowledge, experiments were limited to 400 steps.

Furthermore, qualitative analyses were of prime interest, because this model is yet too simple to draw quantitative conclusions. Thus, the method of systematically varying the parameters was preferred, because it is compatible with maintaining the main assumptions instead of pursuing statistical approaches. In fact, each decision-making pattern was directly matched to random processes, and tendency to cheat was constantly compared with honest agents' configurations.

3.7 Performance indicators

In this work are investigated the performances at industry and segment level, thus excluding those related to the course of single firms. The main index used is the average profit in thousand of euros that reaches its maximum when all firms use a full quality supplier. Notice that because suppliers were assigned random quality values according to a uniform distribution between 0.5 and 1 (see Table 1), industry has a relative maximum when firms are able to identify all the satisfying suppliers that are over the 0.75 threshold quality. When this situation occurs, each segment produces an average profit of around 300 thousand of euros, corresponding to 0.875 average quality that is the middle point between 0.75 and 1.[3] Similarly, the worst performance emerges when clients select only suppliers below the 0.75 quality. This situation results in around 0 average profit. Notice that FP and FT average profits vary within the same range. To have a relative measure of profit, in next analyses the ratio between average and maximum profit is reported (% AP/Max AP). This index varies among 100%, when average profit is maximum, and 0%, when average profit is at the lowest level.

Because of cheating behaviors, the profit losses (% PL) are also reported as the percentage variation of profit among industry where firms do and do not cheat, both with 0.50 and 1 probability. For example, % PL in INDEBT.5 is the percentage variation among INDEBT0 and INDEBT.5 average profit. Similarly, the INDEBT1 % PL is the percentage variation among INDEBT0 and INDEBT1 average profit.

[3] Indeed, because virtual experiments start from a random uniform distribution, and because of decimal approximations, in some experiments it is possible that maximum average quality reaches 0.89 and maximum average profit 315.000.

To understand which type of information agents rely on, the number of times each decision-making process is actually used is counted. More specifically, the percentage of use of each device is reported as the ratio among the number of times each device is used and the total amount of choices.

In the following tables, the labels are as:

- % DEBT, the percentage of times a decision based on DEBT memory is activated based on the total number of decisions;
- % INDEBT, the percentage of times the INDEBT decision making is activated based on the total number of decisions;
- % REBT, the percentage of times the REBT decision-making is activated based on the total number of decisions.

4 Results and hypotheses testing

4.1 Results at industry level

The first group of hypotheses is articulated as follows: (hypothesis 1a) in the medium-long run (that is, in a stable regime) honest agents bring industry profitability to its maximum, while (hypothesis 1b) dishonest agents cannot, and (hypothesis 1c) there are differences depending on agents' decision making patterns, and (hypothesis 1d) attitude to cheat. All of them are fully confirmed for the smallest industry size (Table 2), because honest agents reach the maximum performance, the different decision making patterns lead the industry to different outcomes, and increasing cheating attitude produces a profit decreasing. For the two major sizes the H1a hypothesis is not confirmed, while the others are.

Clearly, many performance variations are explained by industry size, which leads us to the second group of hypotheses. They suggest that: (hypothesis 2a) in larger industry size there is a lack of profitability; (hypothesis 2b) this latter increases dramatically if agents are dishonest; and finally (hypothesis 2c) direct experience counts much less in larger industries. All these hypotheses are confirmed (Table 2).

Another result that it is possible to grasp from the analysis at industry level (Table 2) is that, if agents trust only their own experience avoiding others' information regardless whether accountable or not, they can achieve collective maximum performance only in small size industries. Moreover, it is noteworthy that, ceteris paribus, such decreasing is absolutely nonlinearly correlated with size growth: by increasing size four times from 50 up to 200 agents average profit decreases 7 points, while a further growth of 10 times determines only 2 points less. It is also noticeable that such a nonlinear effect regards all the types of decision-making patterns, but, quite strangely, with a special incidence when agents are honest. Consequently, the losses of industry profitability due to the size effect are minor in two cases: i) when agents are honest and exchange information, because INDEBT0 and REBT0 losses are respectively 5 and 6 points respect to 24 with INDEBT.5 and REBT.5 or INDEBT1 and REBT1; ii) when agents do not exchange information at all, because the losses are respectively 27 and 26.

Table 2 Performance at industry level

Decision making patterns	% AP/Max AP Stable regime Industry size			Time to reach a stable[a] % AP/Max AP Dynamics Industry size		
	50	200	2000	50	200	2000
RND	53	49	48	–	–	–
DEBT	99	92	90	16 (100)[b]	48 (91)	22 (88)
INDEBT0	99	95	94	14 (100)	19 (94)	26 (92)
INDEBT.5	97	88	73	29 (100)	–	58 (71)
INDEBT1	95	84	68	–	–	64 (67)
REBT0	100	95	94	12 (100)	31 (94)	24 (91)
REBT.5	96	85	72	–	–	61 (71)
REBT1	94	84	68	–	–	57 (66)

[a]Performance is considered stable when it does not move from the mean for more than 3%

[b]Value of %AP/Max AP at that specific time

There are two main reasons for explaining these nonlinear effects. The first one refers to the relationship between agents' cognitive capacity and industry size, because an increase of internal knowledge—that is of the number of questions they could ask each other—or of external knowledge—that is of the number of transactions they can establish in each interval—would impact differently on industry profitability (Biggiero 2009a). The second reason is that, as it is showed by the time to reach the stable dynamics (Table 2), "real" uncertainty becomes higher in 200 rather than in 2000 agents' industry size. This phenomenon concerns only the segment of FT, which in fact contributes to the relatively less bad results in the larger size (the detailed explanation is below in Sect. 4.2.B).

Data shows therefore that, if agents are honest, the effects of industry size are not heavy, especially when they exchange information. Conversely, the effects of opportunism are dramatic, though not proportional to the growth of industry size, because losses of profitability grow 5 times respect to an increasing of 40 times of the number of agents. Hence, *for industry profitability opportunism is more dangerous than size*.

However, the combination of the two effects acts nonlinearly on industry profitability, because moving from the smallest to the largest size and from the honest to the half and full dishonest agents the losses increase from 4 to 11 and 26 points and from 6 to 11 and 26 points for agents using respectively only the INDEBT and REBT decision making patterns. Hence, the combined effects of these two damaging factors is more than proportional of their individual effect.

It is noteworthy that in all configurations of the largest size or with full cheaters in any size reputation is never adopted as the selection device. In the case of the largest

[4]There is a percentage of RND decision making use that is not reported in Table 3 and in next Tables 4 and 5. For each decision making pattern, this percentage of RND use can be computed as the difference between the 100% and the sum of percentages of DEBT, INDEBT and REBT uses.

Table 3 Profit loss and percentage of use of each decision making[4]

Decision making patterns	% PL			% DEBT			% INDEBT			% REBT		
	Industry size			Industry size			Industry size			Industry size		
	50	200	2000	50	200	2000	50	200	2000	50	200	2000
RND	–	–	–	0	0	0	0	0	0	0	0	0
DEBT	–	–	–	99	93	92	0	0	0	0	0	0
INDEBT0	–	–	–	98	92	67	2	7	31	0	0	0
INDEBT.5	2	8	22	94	84	59	5	13	39	0	0	0
INDEBT1	4	12	28	93	84	68	5	12	29	0	0	0
REBT0	–	–	–	82	79	67	1	6	31	16	13	0
REBT.5	3	11	23	90	78	58	6	17	40	3	2	0
REBT1	5	12	28	92	85	68	6	11	29	0	0	0

size the reason is that too few agents acquire direct experience and so the transmitted information is too scarce to create many convergent evaluations. The ones that emerge are not enough to be chosen. Fully dishonest agents in the two minor industry sizes are soon recognized as unreliable and, moreover, their evaluations hardly converge on credible suppliers. Likely, the few and false reputations are over time belied by agents' direct experience. Hence, they are formed but not selected to decide.

The use of indirect experience-based trust grows with industry size, but much less than proportionally, and it occurs by eroding direct experience-based trust. However, this latter in no case becomes marginal, because it stands always over the 58% share. The same phenomenon takes place as consequence of opportunism, as we can see by reading Table 3 vertically. A significant change of DEBT can be recorded only between the extremes of full honest and full dishonest agents in the smallest and middle size. Conversely, between full and half honest agents or, regardless of their cheating attitude, into the largest size there are no significant variations. Therefore, the hypothesis H2c is confirmed too.

Previous data enable to confirm the third group of hypotheses, which is articulated as follows: (hypothesis 3a) the damage in terms of lack of industry profitability provoked by opportunism is not proportional to the cheating attitude; (hypothesis 3b) it is much higher between zero and half cheating than between half and full cheating; and (hypothesis 3b) the non-proportionality of the effects of cheating attitude is higher in larger than in small size industry.

If we move to the right side of Table 2 concerning the dynamics of industry profitability, the most interesting result promptly appears: only in the largest size there is stability in each decision making pattern. Hence, although we know that the average performance is always lower than in the smaller sizes, it has the advantage to find always a stable regime. The most unstable size is definitely that of 200 agents, as it is confirmed also by other studies (Biggiero 2009a).

Previous results suggest that each virtual experiment produces a specific path of performance, and it draws a unique history of industry. Attention should be paid to the fact that in each step a whole cycle of information gathering, alternatives comparison, supplier selection, order placement, production process, product delivery, and

payment is supposed to be finalized. In the real world, even for very simple products in large and contendable markets, this whole cycle would take at least 4–5 weeks. In a further extreme simplification, it could perhaps be supposed that a step represents a week, which implies that 200 intervals addresses to about 4–5 years. It is important to bear this in mind when analyzing these results, because, lacking any product or actor change, the world depicted in this model is still very simple.

Noteworthy, stability is reached quite soon or not at all, because it is achieved always before the 65th interval, and except for the cases of dishonest agents in the largest size, before the 50th interval. It means that, in the stylized correspondence with a real-time industry above addressed, in about one year a stable path will or will never more emerge.

Results on dynamics allow to test the fourth group of hypotheses, which can be summarized as follows: (hypothesis 4a) without opportunistic behaviors the decision making patterns exploiting indirect experience give a superior performance in terms of speed to reach a stable performance; however, (hypothesis 4b) if agents cheat such a superiority is reduced; and finally (hypothesis 4c) in presence of large industry size the advantages of decision making patterns exploiting indirect experience are stronger.

The first hypothesis is confirmed only in the smallest industry size, and becomes particularly marked with 200 agents, when the gap reaches 30 intervals. Nevertheless, that hypothesis is not confirmed in the largest size, where the huge information space lightly reduces the efficiency of indirect information, even if it ensures a higher profit respect to direct experience. Consequently, the hypotheses H4b and H4c should be rejected too, because, when the comparison between the different alternative regimes is possible, the largest size industry takes the double time of the smallest to reach a stable performance, and this holds regardless of any possible opportunistic behavior. Hence the circulation of information about agents' own experience and reputation do not allow to reach a sooner performance in large industry size.

These results are also confirmed by Figs. 4, 5 and 6 reporting the average profit dynamics. They suggest that each virtual experiment produces a specific path of performance, and it draws a unique history of industry. In particular, results (Fig. 4) show that: i) RND choice oscillates around the 150 average profit corresponding to the 0.75 average of supplier's quality; ii) DEBT brings around the best performance only in the small size industry; iii) INDEBT and REBT strategies reach maximum average profit more quickly, even if INDEBT occasionally suffers some slight decrease. By increasing industry size up to 2000 firms this advantage becomes more evident: DEBT permanently produces a worse performance than those scored by INDEBT and REBT.

Figure 5 reports effects of different inclinations to cheat in industries where INDEBT decision-making pattern is activated. In the 50 firms industry, it emerges how cheating deeply worsens performance by keeping average profit away from its maximum with oscillations of different wideness. When industry is composed by 200 or 2000 firms the cheating effects became much more destructive and industry stability becomes poor. The point is that increasing the industry size causes the enlargement of information space, which makes the role of indirect experiences much more strategic,

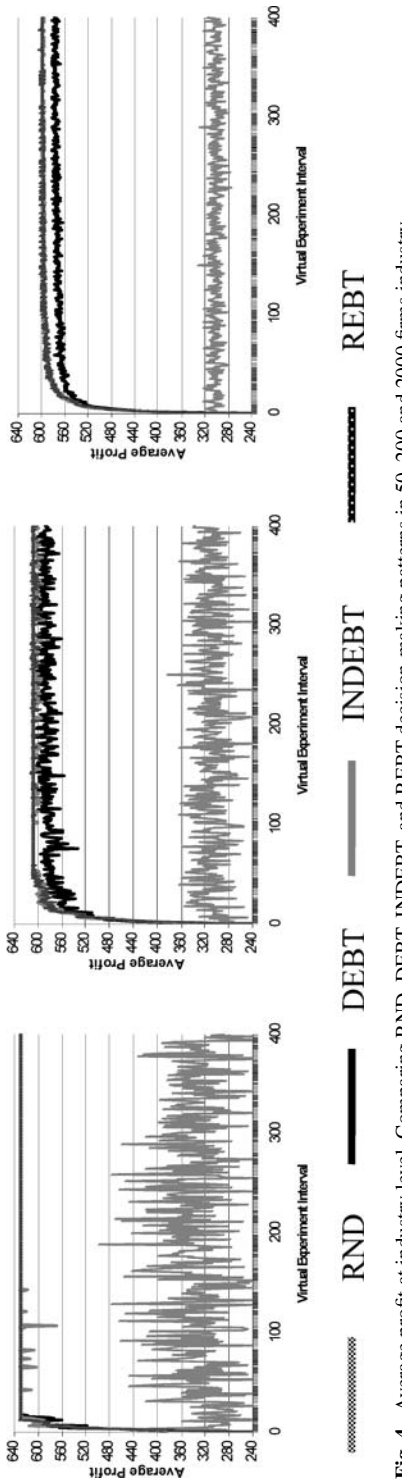

Fig. 4 Average profit at industry level. Comparing RND, DEBT, INDEBT, and REBT decision-making patterns in 50, 200 and 2000 firms industry

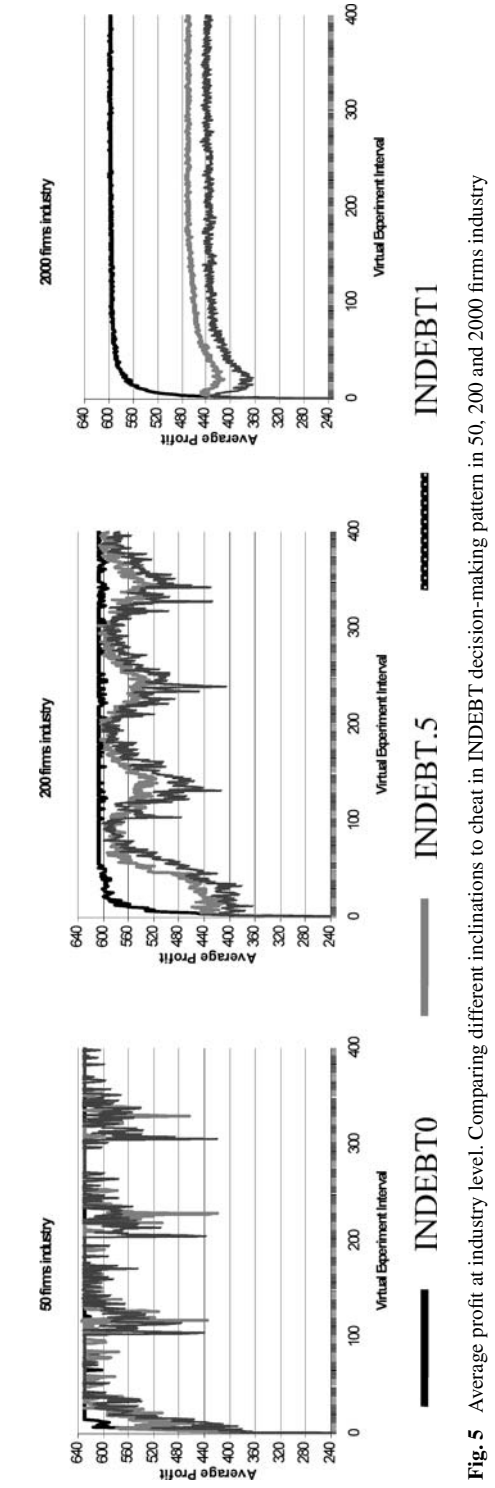

Fig. 5 Average profit at industry level. Comparing different inclinations to cheat in INDEBT decision-making pattern in 50, 200 and 2000 firms industry

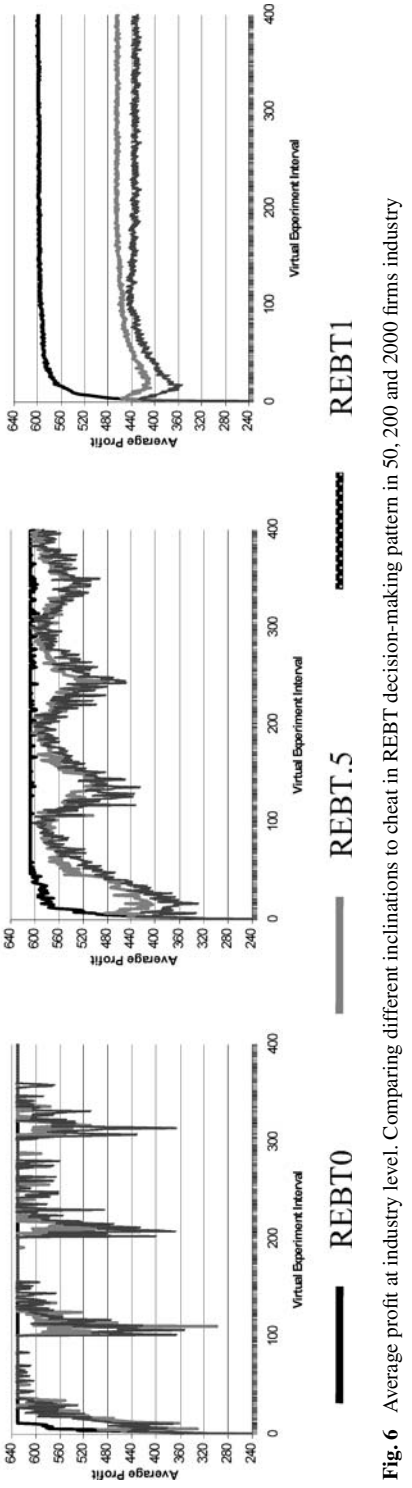

Fig. 6 Average profit at industry level. Comparing different inclinations to cheat in REBT decision-making pattern in 50, 200 and 2000 firms industry

Table 4 Final producers

Decision making patterns	% AP/Max AP		% PL		% DEBT		% INDEBT		% REBT	
	Industry size		Industry size		Industry size		Industry size		Industry size	
	50	2000	50	2000	50	2000	50	2000	50	2000
RND	52	48	–	–	0	0	0	0	0	0
DEBT	100	91	–	–	99	93	0	0	0	0
INDEBT0	100	94	–	–	97	37	2	61	0	0
INDEBT.5	97	55	3	41	93	25	6	74	0	0
INDEBT1	96	48	4	49	94	47	5	53	0	0
REBT0	100	94	–	–	66	37	2	61	32	0
REBT.5	96	53	3	43	89	23	6	76	4	1
REBT1	95	47	5	50	93	46	5	54	0	0

but at the same time it makes the firms much more sensitive to cheating behaviors. In the small size industry, decrease in performance is less evident because FP is able to recognize all unreliable informers and to avoid them in their next decisions.

Another interesting result is that when agents are cheaters, REBT performance (Fig. 6) is poorer than INDEBT performance (Fig. 5). It suggests that when REBT decision making is activated, wrong reputation damages have to be added to those of false information, thus the depressing impact of cheating on performance becomes much stronger. It means that false information produce false reputations that in turn decrease firms' profitability even further.

4.2 Results at segment level

4.2.A Final Producers' segment

Honest FP When agents are honest, maximum average profit is reached through all the types of decision-making patterns, except the random one (Table 4). In each decision-making pattern direct experience choice (% DEBT) is always the most important decision-making process. However, when reputation is allowed, this covers 32% of choices (% REBT). Indeed, between the two forms of decision-making patterns based on indirect information there are no significant differences: using or not using reputation does not give any specific advantage.

Cheating FP When agents cheat, the smallest industry suffers 3–5% of profit loss, depending on half or full propensity to lie. It is interesting to note that when cheating attitude is 50% instead of 100%, agents increase their confidence on indirect experience-based trust (% INDEBT), thus they explore higher portions of information space, evaluate a major number of suppliers, and store a larger amount of knowledge. This is because the attitude to tell the truth half time respect to never forces agents to get more evaluations on suppliers.

Size effects Large size with honest agents worsens industrial performance: with 2000 agents, direct experience allows 91% of average profit (DEBT0), which can reach 94% only through indirect information (INDEBT0 and REBT0). The recourse to indirect experience decision-making process (% INDEBT) increases enormously with respect to the smallest industry size, approximately 10 times in both the indirect experience-based and reputation-based decision-making patterns. This is because direct experience can cover only a very small portion of the wide decision space. On the contrary, in REBT experiments the number of choices based on reputation (% REBT) is around 0, because reputation cannot be formed, experience being too dispersed among agents.

Cheating attitude destroys industry profitability, which drops down to 55 and 48%, with half and full propensity to lie. With respect to the situation with honest agents, ceteris paribus cheating behavior provokes 41 and 49% profit loss, respectively. Cheating behavior becomes so important just because circulating information increases sharply. As in the case with honest agents, for direct and indirect experiences are too dispersed into the industry, reputation almost does not form, and the (bad) game is played only by taking recourse to indirect experience decision-making process. In sum, when agents cheat, others should not be trusted, especially in large information spaces, because the eventual capability to identify wrong information does not compensate the damage provoked by cheating.

4.2.B FT segment

FP and FT seek the same goals, and obey the same rules of suppliers' selection. Notwithstanding, under some circumstances performances sharply differ, because of the following two differences between the two segments: 1) though the same *number* of clients make decisions on the same number of suppliers, the number of intermediary agents is double; 2) *which* agents are activated in each step depend on the FP segment. This latter condition evidences the relationship between the two segments, which, on the other side, are completely autonomous. To understand how these differences play, it is better to distinguish the analysis in the small and large size (Table 5).

Honest FT The maximum performance possible in both segments has almost no variation (Table 5), with some very small differences coming only from the fact that FT reach maximum in 15 instead of 7 steps, after which both segments remain stably at maximum performance. However, there are significant differences in the ways such performances are reached, especially when indirect experience-based decision-making processes are allowed. FT reduce the use of others' information (half % INDEBT choices) and firms explore a smallest portion of information space. Hence, "cognitive efficiency" grows considerably, because FT achieve the same performance of FP by activating less informers, using less information, evaluations, and knowledge. In the reputation-based decision-making pattern, nothing changes very much, if not for the fact that, with double the number of informers with respect to clients, reputation cannot be formed at all.

[5]For each index comparison is done by (FT-FP)/FP.

Table 5 First tiers compared to final producers. Percentage differences of FT indexes respect to FP indexes[5]

Decision making patterns	% AP/Max AP		% PL		% DEBT		% INDEBT		% REBT	
	Industry size		Industry size		Industry size		Industry size		Industry size	
	50	2000	50	2000	50	2000	50	2000	50	2000
RND	2	1	–	–	0	0	0	0	0	0
DEBT	0	−2	–	–	0	−3	0	0	0	0
INDEBT0	−1	0	–	–	1	159	−50	−97	0	0
INDEBT.5	1	66	−50	−93	2	272	−33	−95	0	0
INDEBT1	−2	84	27	−88	−2	91	0	−91	0	0
REBT0	0	0	–	–	48	159	−50	−97	−100	0
REBT.5	0	72	−12	−95	2	304	0	−95	−50	−100
REBT1	−1	87	9	−88	−2	96	20	−93	0	0

Cheating FT When agents cheat half the number of times, results do not change significantly[6] for both indirect experience- and reputation-based decision-making patterns, except that efficiency does not increase so much as in the other circumstances. When all agents cheat, though there are no performance variations, agents are induced to use a little bit more indirect information, because it comes from agents who had at least some few experiences. However, after checking their evaluations, these informers are soon recognized as unreliable. The final effect is to slightly reduce efficiency advantages obtained when comparing FP and FT with honest agents. Reputation is formed in both segments, but it is never chosen because direct experience is so large that this wrong reputation is always referring to known suppliers.

Size effects Things radically change when considering FT in an industry size of 2000 half or full cheating agents, because average profit increases respectively 66 and 84% with INDEBT, and 72 and 87% with REBT decision-making patterns (Table 5). Consistently, profit losses almost disappear and FT segment reaches its possible maximum. Evidently, because of rather counter-intuitive effects, FT characteristics "immunize" against the damages of cheating. The main factor producing such effects is the disappearance of indirect experience-based decision-making (% INDEBT) with respect to what happens in FP segment.

The explanation is that by doubling the number of FT with respect to FP, in FT segment a large part of informers do not realize any direct experience, and thus they cannot pass any information. Then, when FT activated by FP interrogate such never-activated informers they do not receive any information or reputation, and therefore they retrench on their direct experience. Conversely, in the FP segment, all informers realize their own experience and so they can pass it and induce a huge informer's memory. In both segments, there is communication, but between FT there is very few to be communicated and over time becomes lesser, even because of forgetfulness

[6]The interpretation of some high percentage should be moderate by considering that for some indicators absolute values are very small. For instance, this is the case of PL and INDEBT.

effects. Consequently, there is no reputation, which depends on INDEBT memory, and no random choice, which over time disappears.

Therefore, one can say that the segment of FT benefits from the capabilities of FP, because it is "sterilized" against bad information and opportunism. Hence, these results do not verify the first hypothesis of the fifth group (hypothesis 5a), because with opportunistic agents the collective performance of intermediate agents is as well as that of FP when industry size is small, and higher when size is large. The hypothesis 5b is not confirmed too, because in larger industry size FT collective performance is better than that of FP, especially with cheating agents. Finally, with opportunistic agents and in larger industry size the collective performance of intermediate agents overcomes that of FP, but if only one of the two factors is absent the performances of the two segments are nearly equivalent. Thus, also the hypothesis 5c is not confirmed by the virtual experiments.

5 Model validity and docking

The validation of the previous results is limited by the lack of strong empirical evidences. By using analytical models mainstream economics showed recently a growing interest on cheating behaviors generally related to situations in which individuals act illegally to improve their positions (Krakel 2007; Berentsen et al. 2008). In agricultural economics some authors refer to cheating as the farmer opportunity to misrepresent the quantity of production (Giannakas and Fulton, 2000, 2003), while in environmental studies as the violation of governmental regulations (Rege 2000; Garvie and Keeler 1994). Others study cheating in price strategy, in financial statements, in oil production assessment, in technology-trading coalitions and in policymakers announcements strategies. Even if some of these works deal with cheating effects, they do not analyze profit losses due to cheating and do not deal with inter-firm relationships. Thus they are not directly comparable with the results of this paper.

Our model confirms suggestions coming from management literature (De Jong and Nooteboom 2000; Hall 1992; Martinez and Norman 2004; Sako 1998), because, regardless of their actual quality, suppliers about which reputation has been formed (and passed) have been engaged more often than others have. These effects are more marked in the middle size industry, because in the smallest one all good suppliers are known, and consequently, due to the ratio between clients and suppliers, they always work. On the other hand in the largest industry size, with the parameters actually working in our model, almost no reputation is formed. Likely, things would significantly change whether the ratio between clients and suppliers were much lower or by increasing (and differentiating per size) agents' computational capacity to ask and elaborate information.

Sako (1998) analyzed a large dataset related to 1415 first-tier component suppliers in the automotive industry in Japan, the US and Europe in 1993–1994. He found a positive relationship between trust and economic performance (cost reduction and profit margins). Remarkable country differences were also recorded as concerning the significant types of trust—contractual, competence, and goodwill trust—and the size of the positive effects. However, quite interestingly and surprisingly, through an

extensive secondary analysis of the same data De Jong and Nooteboom (2000) drew that the causal structure among the most salient variables—behavioral uncertainty (trust), customer commitment (loyalty) and uncertainty avoidance (trust behavior)—seems similar for the US, Japan and the EU.

Besides these empirical researches the most comparable studies with the present one are constituted by other simulation models. Hence, the discussion of validation should turn into a docking analysis (Burton 2003) that compares the CIOPS results with those suggested by simulation models, whose structures and purposes we have already outlined in Sect. 2. Indeed, only few models consider the role of reputation and indirect experience and only one directly examines the impact of opportunism on profit and modeled opportunism in terms of cheating. Most of them put trust at the focal point and eventually analyze some of the determinants and consequences of trust and opportunism but not profit or other pure economic or financial outcomes.

Our findings are consistent with Lin and Li (2003), who found that "organizations can benefit from competency-based trust mechanism under incorrect information conditions". As well consistency holds with Prietula's (2001) results: in both models indirect experience-based trust increases more than proportionally effectiveness and efficiency in larger group (or industry) size. Further, with a 50% cheating agents "groups took significantly more time to complete the task, with more organizational effort, and found a lower percentage of the items".

Though in principle viable also for this aim, the computational model built by Klos and Nooteboom (2001) and its successive development (Gorobets and Nooteboom 2004) were not really dedicated to investigate the relationship between trust and profit or between opportunism and profit loss. The aim was in fact analyzing how the degree of product differentiation, asset specificity, and scale economies affect supplier-buyer joint profits. In this perspective trust is studied as an emergent phenomenon. This model confirms some of the crucial predictions of transaction cost economics: the higher the product differentiation, the more internalized the production and the less pronounced the trust attitude. In this approach, trust is the agents' adaptive function, and opportunism is modeled as the attitude to betray previous or current agreements. The aspect of information circulation is not dealt with at all, and thus, agents are supposed to make decisions only based on their direct experiences. Moreover suppliers do not differ in terms of quality but only in terms of *given* buyers' preferences. On the other hand the model is quite effective and fine in considering structural and economic aspects of inter-firm relationships. Some way, it is complementary to CIOPS model, which is not detailed in these issues but conversely quite sophisticated in agents' cognitive properties and in dealing with information transfer. However, its complementarity prevents now any direct and strict comparison.

Besides some theoretical and implementation differences, Giardini's et al. (2008) focus on the same issue of ours: the effects of cheating on the performance of a set of agents. Their results are consistent with ours excepted the one concerning FT performance, which in their model is always lower than that of FP, while in our model FT perform as well as FP with honest agents and better with cheating agents, and far better when industry size is large.

Notwithstanding the differences underlined in Sect. 2.2, Tychonov's et al. (2008) results show two interesting similarities with ours. The first one is that opportunism

produces cheating and this in turn profit loss due to the engagement of tracing agents, who become necessary to reduce the impact of cheating but are costly. The second one is that the distance between the results obtained with half and full cheating agents in both models is not as wide as it could be expected. In their model it means that with full cheaters "the delicate equilibrium between trust, tracing frequency and honesty is reached sooner" (p. 18), while in our model agents' cognitive efficiency grows due to the fact that they recognize much sooner unreliable informers and hence turn on trusting only their direct experience or eventually reputation.

6 Limitations

The limitations of this work are linked to the difficulty of empirical validation and the simplicity of some model's features. In this section the two groups of limitations are discussed separately. By beginning from the first group, due to the difficulty to operationalize the main variables and to find comparable cases, empirical research on inter-organizational trust is disproportionately lower than the corresponding theoretical literature. In this small set the studies explicitly addressing and measuring the economic impact of opportunism are even fewer, because most of them deal with structural and technological variables, as transactions' specificity, frequency or uncertainty, the number of exchanging parties, and eventually their perceived effects on economic outcomes. Moreover, most of them do not take into account the crucial role played by information processing in moderating the effectiveness of trust (Carson et al. 2003).

In mainstream economics there are some theoretical models, which try to analytically draw some indications, and other works cope with these issues through game theoretic approaches (the so-called trust games), but its structure produce results quite incomparable with ours, because they focus on very specific and narrow questions and no one deals with supplier-buyer relationships and neither with outcomes explicitly addressing profit losses.

Consequently, further empirical researches are required to improve the CIOPS validation with empirical evidences. A first method could be to study two or more strictly comparable industries involved in the same business where cheating behavior is present or absent. In this way, it will be possible to look for plausible connections between opportunism and economic performance and to find some opportunism outcome. Otherwise, model validity could be increased with a forward explanation (Burton 2003) by comparing the modeled mechanisms with the observed firms' communication styles and decision-making strategies. This is the case of recent works carrying out a survey in the aerospace cluster (Biggiero 2009b). These studies allow to conveniently verifying how much and in what conditions firms rely on information coming from direct experience (DEBT), indirect experience (INDEBT), and from reputation (REBT). They could also offer suggestions for cheating behavior and retaliation strategy that could be properly exploited to improve the model. When the validation has been improved, the field analysis could conveniently indicate the industry features that have to be inserted as parameters of CIOPS model. This way, the model could actually work as a useful predictor of a given real world industry.

The second group of limitations concern major and minor assumptions, some parameters setting and architectural features of the model. As we anticipated in Sect. 2.1, the major assumptions are that: i) agents are all equal in terms of size, cognitive capacity and boundaries, selection devices (decision making patterns and processes); ii) their cheating attitude is invariant; iii) their memory, and thus their knowledge growth, is undermined by four forms of forgetfulness; iv) the sole form of product differentiation is between industry segments, that is between raw materials, intermediate goods, and final products; and finally v) there is no firms' turn over, and therefore failed or inadequately profitable firms do not exit and new ones do not entry.

It is indeed impossible to outline the implications of these assumptions for the possibility to generalize the results here discussed, because complex phenomena hide quite surprising outcomes, which hardly could be intuited without running specific virtual experiments as those realized in this work. At the best, just some conjectures could be raised and offered for future tests. Bearing this warning in mind, here we attempt to draw some of them, at least trying to figure out the direction to which each of these assumptions points out. The invariance of agents' behavior in terms of cheating attitude could help them being very efficient in selecting suppliers, because otherwise their strategies would be subjected to much more uncertainty. Likely, this could keep industry profitability higher than what we found in these experiments. The same holds for the fact that the only form of product differentiation is that between segments, because this simplifies suppliers' selection. On the opposite direction plays the absence of firms' turn over and evolutionary mechanisms, because the permanence of unprofitable firms depresses industry profitability. As well occurs for the forgetfulness effects, which, especially with dishonest agents, prevent their knowledge growth. However, without making the appropriate experiments it is impossible to confirm these conjectures and neither to say whether these effects compensate each other or how they could combine in some unexpected way. Moreover, removing the assumption of agents' uniformity and introducing a retaliation strategy and a more sophisticated learning process than the one implemented here would likely undermine the stability of dynamic patterns and hinder the achievement of high average profits.

The list of minor assumptions is much longer than that of the major ones, and so we mention just a few of them: i) the technology is only sequential, and so we don't know what could happen whether segments were connected through parallel or reciprocal interdependencies; ii) opportunism is meant only in terms of cheating and not in terms of betraying previous (formal or informal) agreements; iii) information is costless; iv) there are no stocks and no fixed capital goods; v) agents ask only their competitors and not also suppliers or customers; vi) there are no inter-firm alliances; vii) there is no pure gossip, that is (individual) de-responsible information, else than (collective) reputation; viii) agents lie only in relation to information content (true or false, the worst for the best advice) and not to its nature (existing for non-existing) or type (direct for indirect experience or reputation). As evident, it is definitely impossible to draw any kind of conjecture about the possible effects of removing these assumptions. The only way is to methodically run the appropriate virtual experiments, and actually this is the strength and incomparable value of

the simulation model methodology, because it would be as well impossible to find enough and clear and methodologically comparable case studies able to understand and isolate the effects of each assumption.

The same story holds for the second group of limitations, which concerns parameters' setting, because it is well known that a property of complex systems is being sensitive to its (even small) variations. For instance, what could happen whether the reputation threshold or the informers' reliability threshold would change? And what about variations in the aspiration levels, that here have been fixed at 0.75%, or in the forgetfulness time or mix? Here something more precise can be said just concerning the ratio 1/2 between FP and FT, and the one-to-one relationship between each pair of supplier-buyer, just because recently CIOPS model was developed in that direction. Biggiero (2009a) found that, by varying the ratio of transactions between the suppliers and the buyers—which actually is the key parameter for measuring the competitive balance between the agents of the two segments—, the increase of the number of subcontractors activated by each client impacts very differently on FPs and FTs. The former gain a lot, while the latter lose considerably both in terms of profitability and number of firms. On the contrary, accessing more others' experience by means of asking more informers helps more FTs than FPs. However, in both cases the marginal benefit decreases, and the net effects at industry level strictly depends on the combination of the two factors. Moreover, uncertainty and instability sharply grow because of the consequent higher competitive pressure among a small number of clients respect to that of suppliers.

If it is true that (by now) the docking analysis shows that our model results are consistent and largely aligned with other simulation models focused on the effects of trust and opportunism, there are reasons to suspect that this large convergence significantly depends on the fact that the theoretical expectations currently available are based on relatively simple empirical research and simulation models. On one side, these considerations sound discouraging for reaching soon a deep understanding of these crucial issues in organization science, but on the other they assume a great relevance into the debate on the advantages of geographical and cognitive proximity for territorial systems. In fact, knowledge sharing and social mechanisms preventing opportunism are commonly considered among their most crucial factors of success. However, despite these general beliefs and many policy interventions grounded on them, field research produces a lot of evidence that in many cases these factors are not sufficient neither to trigger nor to maintain acquired competitiveness. Further, some studies show that many territorial systems are successful without or with a small extent of these crucial factors.

The complexity of the relationships between information transfer, trust, agents' behavior and industry structure evidenced by our model can give an idea why the variety of territorial systems in size, structure and other variables makes this debate still inconclusive and so many empirical cases seem supporting contradictory theses or appear quite inexplicably (Brenner and Mühlig 2008; Gordon and McCann 2000; Martin and Sunley 2003). The same sense of inconclusiveness of empirical research and underlying complexity emerges from the literature on the relatively less complex issue (respect to that of territorial systems) of inter-organizational networks to which we have extensively referred in this paper. Likely, the reason is just that the relationships between socio-cognitive and structural variables are much more complex than

what has been supposed until now. The great support given by agent based simulation models like the one we presented here is that they make possible testing and formulating research hypotheses and investigating theoretical relationships without incurring into the huge costs and methodological problems of incomparability raised by empirical and field research.

7 Conclusions

By simulating the complex interactions occurring between multiple agents linked by cognitive and structural relationships and by testing five groups of hypotheses, the CIOPS model demonstrates, under a set of assumptions, the following issues. The most general one is that trust and opportunism significantly affect industry profitability. Depending on agents' use of others' information, on their cheating attitude and on industry size, profit loss varies between 3% and 50%. This result confirms theoretical suggestions and empirical findings coming from economics and organization science on transaction costs: even if there are no information costs and rationality is only lightly bounded, costs of trust misplacement and opportunism can severely damage performance at industry level. In this sense, a crucial point concerns industry size, and hence information space: as it grows, the negative effects of cheating dramatically increases too. Hence, a general implication could be advanced: when agents work in large industries, it is better to be more prudent in trusting others.

The second main result is that, when all agents behave in the same way and have the same structural and cognitive characteristics, there are no relevant differences in cheating gradation, whether half or full time. This has the very relevant implication that it is much more important and easier to prevent that a social network loses prevalent honest behavior than trying to restore or improve collective performance coming from a context of deteriorated honesty. In other words, the two extremes are definitely not symmetrical in terms of its effects and efforts required to move collectivity towards the same outcomes.

The third result shows that, although direct experience alone allows achieving near-maximal performance, with honest agents the exploitation of indirect experience and reputation brings performance to the maximum and in a faster manner than by using only direct experience. This finding reinforces the role played by trust, and the usefulness of the factors that, in a given environment, favor information circulation.

The fourth interesting suggestion is that, in the presence of opportunistic behaviors, it would be much better that direct experience were concentrated in a few agents, because its uneven distribution would limit informers' damaging power. Indeed, this finding depends strictly on the assumption that the agents in this model are allowed to lie only in relation to information content (true or false, the worst for the best advice) and not to its nature (existing for nonexisting) or type (direct for indirect experience or reputation).

The fifth interesting result refers to the sharp difference in performance that can occur to segments within the same industry. Even if they are submitted to the same cost structure, mechanisms, and threats, the feedback coming from downstream firms could give a strong advantage to the segment of intermediate goods. Hence, the more

segmented the industry, the more uncertain its performance and the process of resource allocation and future transformations.

The sixth finding indicates that the larger the industry the sooner and deeper the performance stabilizes. Especially when agents pass and use others' information, in the smallest size periodic shocks because of forgetfulness effects delay stabilization even beyond the 400^{th} step, though with a constantly narrower oscillation. This means that for small industries the advantage of keeping higher average profits is paid at the price of much more uncertainty.

The main direct theoretical implications of these results for organization science are the following. Firstly, it is further confirmed that trust and opportunism are crucial factors in interorganizational relationships and networks. Secondly, trusting behavior and information circulation give advantages at industry level only if agents are honest. Hence, they are not a positive value per se. Thirdly, scale matters a lot, because agents' number (industry size) can reinforce or hinder collective gain of trusting or opportunistic behaviors.

These findings come from what we consider our most general contribution to organization theory, evolutionary and cognitive economics, and management studies: a clear formalization of the relationships linking information availability, trust and opportunism, and industry profitability. In this perspective, the most common idea that information circulation is always positive for the whole set of agents has been challenged, showing that it depends on trust, opportunism and industry size. Hence, these relationships appear much more complex then what is usually suggested in current organizational, management and economic literature.

Limitations of this work are due to model simplicity and validation difficulty. Empirical researches could allow the improvement of both the architecture and the validation of the model. Moreover, once the validation has been increased, field surveys could conveniently help the parameters setting and make the CIOPS model rightly applicable to real world scenario as a predictor tool. Notwithstanding these limitations, for three reasons this work contributes to the advancement of scientific literature on understanding the relationships between structural and cognitive variables and on developing simulation modeling. Firstly, the most general results discussed here evidence some basic phenomena that likely will also be confirmed in future studies supported by more complex models. Moreover, they partly confirm existing knowledge formed through other simulation models or empirical research. Secondly, once more advanced models had been implemented, the explanation of its findings will unavoidably require having previously understood the simple causal relationships investigated here. In fact, this type of incremental progress is a necessity for all knowledge growths based on simulation models and experimental science. Finally, CIOPS architecture is already built to enhance such future developments.

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