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Knowledge Management Tools, Inter-Organizational Relationships, Innovation and Firm Performance

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ABSTRACT

The business value of information technology is an enduring research question. This research provides new insights to better understand the mechanisms supporting this relation by analyzing the impact of knowledge management tools (KMTs) on the performances of business units involved in inter-firm collaborative innovation projects. We extend current literature by developing and empirically testing a model where: (1) the use of KMTs is affected by critical organizational variables, (2) KMTs can impact the innovation and financial performances of business units. We find that mutual trust and culture for change do not affect the extent of the use of KMTs, while collaborative experience and naturalness in using ICTs as substitutive of face-to-face contacts have a significant impact. Moreover, we show that a more intense use of KMTs has a direct positive effect on new product performance and speed to market, as well as on financial performance. Yet, only new product performance acts as an indirect conduit linking KMT use and financial performances. This article provides a discussion and perspectives of further research concerning the impact of KMTs on innovation practices in inter-firm collaborative environments.

1. Introduction

The impact of information and communication technologies (ICTs) on firm financial performance has been an enduring research theme in the literature [1,2]. While it is almost unanimously acknowledged that ICTs have changed and improved the effectiveness of organizational processes, existing research provides elusive results concerning the relationship between ICT use and firm financial performance [3]. Several reasons have been proposed to explain this observation. Some authors have argued that it is very difficult to precisely quantify the impact of ICTs on the firms' activities [4], and, as a result, any quantitative analysis has severe limitations. In this context, some researchers have suggested to leave the firm-level perspective and to adopt micro-level units of analysis because they can overcome many measurement issues through a more fine-grained characterization of ICT-driven processes [5]. Unfortunately, few studies have developed these micro-level perspectives [6].

Another important issue considered in this debate is the notion that the impact of ICTs on financial performance is both direct and indirect, and thus we need to investigate the mechanisms that support such links [2,7]. Innovation is a likely candidate for one of these crucial indirect relationships [8]. Indeed, innovation performances – and in particular new product performances or the promptness of a firm to develop new products/services as a response to market needs (also known as "speed to market" [9]) – are considered important strategic resources and sources of higher financial result revenues in several markets [10]. This issue is

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especially important in more mature industries such as the mechanical or the automotive [11] where gradual process of standardization of operational activities has reduced the variance of operational performances across companies and increased the importance of innovation capabilities (see recent studies that explore the role on innovation in mature industries e.g. [6,10,11]). In other words, since operations are no longer distinctive to outcompete in mature industries, firms have to rely on product innovation to gain sustainable competitive advantage [11].

While innovation is increasingly seen as an important source of competitive advantage, an emerging body of work shows that ICTs have the potential to improve the firms' innovation capabilities in multiple ways, for example by increasing design speed or allowing more precise and detailed design activities [10,11]. The contribution of ICTs can be particularly significant for innovation in the context of inter-firm collaborative relationships, a process adopted by an increasing number of firms as a strategy to maintain their innovative competitiveness (see, e.g. [6,10,12]). Among the many information technology instruments currently available in organizations, knowledge management tools (KMTs), i.e. ICT applications that are adopted with the aim of managing organizational knowledge [11], have the potential to increase the outcomes of inter-firm R&D collaborations by improving the quality, the easiness and the degree of knowledge exchange [11]. In particular, they can help inter-firm R&D projects to: a) create a knowledge base where individuals and groups of different organizations can share and store important knowledge and b) facilitate knowledge transfer processes at the intra- and inter-firm levels [7,8,12–15]. This paper focuses on KMTs that can support inter-firm R&D collaborations through improvements in the two aforementioned processes. They include electronic databases and standardized systems for data transfer such as workflows, mailing lists or computer-supported cooperative work [13].

The literature points out that these KMTs can affect financial performances by improving inter-firm relationships in two ways. First, a direct effect can be achieved by guaranteeing more efficient knowledge-based processes and cost reduction [11,14]. A second indirect effect is reached by using KMTs to improve innovation-related drivers of profits, e.g. product and service performance [16–18] or the speed to market performance [19,20]. Although the literature presents extensive research showing a positive relationship between innovative capabilities and financial performances and between KMT usage and innovation capabilities (e.g., [12,13]), there is a dearth of studies that test both the direct and the indirect impact of KMTs on financial outcomes through the mediation of innovation-related variables.

It is worth mentioning that the outcomes of KMTs on organizational processes are directly related to *how* these tools are used [14]. Indeed, while the literature has unanimously acknowledged the positive potential impact of KMTs on organizational activities, some empirical studies have pointed out that organizations can face several difficulties to effectively exploit these tools (see, e.g. [21–23]). Even relatively simple artifacts such as Excel workbooks can be used for quite complex knowledge-based activities [24], and in some cases software applications can reduce the degrees of freedom of individuals and R&D groups and in turn prevent improvements in the effectiveness of innovation activities (see, e.g. [22–24]). In this context, the important role played by organizational factors emerges: variations in aspects such as trust or collaborative experience can affect the degree and the effectiveness of KMT use across firms, as well as that of different business units or departments of the same organization [5,14]. This important observation introduces the second objective of this study, i.e. the analysis of the impact of organizational factors on the use of KMTs.

In conclusion, this research analyzes how KMTs impact the financial performance of business units involved in inter-firm collaborations as well as the role played by critical organizational variables in the exploitation of these virtual technologies. The empirical setting of this paper is the automotive sector and, in particular, business units of first-tier automotive suppliers involved in inter-firm R&D projects. The two research questions this paper will address are the following:

(a) What organizational factors favor the exploitation of KMTs in support of innovation capabilities of a business unit that is intensively committed to inter-firm R&D projects?
(b) Can the exploitation of KMTs impact the financial results of a business unit through the improvement of its innovation performance based on inter-firm projects?

The remainder of this paper is organized in four sections. The first introduces the key constructs of the research and develops the hypotheses. The second section describes data collection, research methodology and the criteria adopted both for the validation of the measurement properties of the constructs and for hypothesis testing. The subsequent part discusses the results followed by the conclusion and implications.

2. State of the art and hypothesis

This section is divided into two parts. The first reviews current theory and develops the critical hypotheses related to organizational factors conditioning the reliance and usage of KMTs in the context of collaborative R&D projects. The second discusses the impact of the usage of KMTs on innovation and financial performance.

2.1. Organizational variables and usage of KMTs

We identify four organizational variables with potential impact on the use of KMTs in the context of inter-firm innovation collaborations. They are culture for change [25–27]; naturalness in using virtual tools [28,29]; collaborative experience [30,31] and mutual trust [32,33]. We selected these four variables because they met three important requirements. First, the existing work has identified them as having a relevant role in the use of KMTs (see, for example, [4,5,14,26]). Second, they were previously noted as potentially impacting the effectiveness of organizations involved in inter-firm relationships (see, for example, [9,11–14,18–20]). Third, previous qualitative research (see, e.g. [6,10]) has shown that these variables have a critical impact on the use of KMTs in

business units, which are the level of analysis used in this study. Indeed, as discussed below, a critical contribution of this study is the exploration of the impact of these four variables on the activities of business units involved in inter-firm activities. In particular, while culture for change and collaborative experience are considered in some studies as firm-level characteristics, other micro-level research has pointed out that significant variations can be found across different departments or business units (e.g. [9,25]). But, few empirical studies have analyzed the impact of these variables at the business unit level and, in particular, in business units involved in inter-firm projects. By the same token, previous studies have pointed out that naturalness in using virtual tools varies across departments and business units according to education levels, organizational function and previous experience in collaborative activities (both at inter-and intra-firm levels)[5,25]. But, again, there is scarce empirical evidence that has analyzed the impact of this variable on the use of KMTs in business units involved in inter-firm activities. Finally, the degree of trust is very important for those business units that are involved in important inter-firm activities. Mutual trust in technological partners can change across business units since two business units can work with different partners or with different groups and departments of the same partner company [32,33]. But, again, current literature has overlooked the impact of trust on the use of KMTs of business units involved in inter-firm collaborations.

Over the last decade, many authors have advocated the importance of a culture that supports an increasing utilization of ICT tools (e.g. [14,25,26]). Yet, the adequate exploitation of the possibilities offered by new virtual technologies can be inhibited by a lack of culture for change in managerial and organizational practices. This can lead to ineffective and limited uses of ICTs [34]. Previous studies have shown that variations in the degree of culture for change across departments and business units can affect the adoption of new technological devices such as e-mails or video-conferencing systems [27,31,35]. Therefore, we expect that a stronger culture for change, i.e. the readiness of a business unit to accept modifications of working methodologies and procedures, will lead to higher levels of reliance and usage of KMTs. Based on the above arguments, we propose:

H1. The higher the level of culture for change, the higher the level of reliance on KMTs.

As the business environment increasingly relies on electronic communication technologies, experience and naturalness in manipulating such tools as an alternative to traditional face-to-face meetings are in themselves a critical need [28]. Indeed, the naturalness in using digital devices in substitution of face-to-face contact – such as video-conferencing systems, telephone, etc. – is recognized as critical for the successful exploitation of new virtual technologies [28,29]. Limited naturalness in using ICTs can prevent the accomplishment of the strategic goals of efficiency, effectiveness and innovation due to the inability to fully exploit the opportunities offered by new virtual tools [26,28,29]. Previous studies have argued that variations in the naturalness in using ICTs can be found across departments and business units according to employees' age, education, functional role inside the organization, etc. [5,27] We consequently expect that those business units with higher levels of naturalness in using substitutive tools for face-to-face relationships, such as the telephone and video-conferencing systems, will show higher levels of reliance on KMTs. Based on the above arguments, we suggest that:

H2. The higher the level of naturalness in using tools substituting face-to-face contacts, the higher the level of reliance on KMTs.

In addition to organizational issues in the focal firm, there are also dimensions across the supply chain capable of influencing reliance on KMTs. One of the more critical aspects is the length and experience of buyer–supplier relationships. Previous studies (e.g. [30,31]) show that collaborative experience matters for the effectiveness of inter-firm relationships. Repetitive interactions with several other organizations help to find the best practices in inter-firm interactions [32]. Indeed, a business unit with a long history of inter-firm projects shows a better ability to interact and to use virtual technologies in the interactions with its current partners [32]. In particular, prior work suggests that KMT-enabled collaborative processes can represent a superior way to develop complex innovation projects involving numerous individuals and/or geographically dispersed groups (e.g. [6,10,11]). Consequently, we expect that higher levels of collaborative experience of a business unit will lead to higher levels of reliance on KMTs in its relationship with technological partners:

H3. The higher the level of collaborative experience, the higher the level of reliance on KMTs.

Trust is another important factor affecting the effectiveness of intra- and inter- firm collaborative efforts [34,35]. It facilitates learning and innovation [32,33], and various scholars and practitioners have advocated it as a necessary ingredient for effective virtual collaborations (e.g. [14,27]). Previous studies have in fact demonstrated that the lack of trust in virtual teams can deter efficient knowledge exchanges (e.g. [34,35]). Consequently, we expect a business unit that has higher levels of trust in its inter-firm collaborative relationships will show higher levels of reliance on KMTs. Based on the above arguments, we suggest the following hypothesis:

H4. The higher the level of mutual trust, the higher the level of reliance on KMTs.

2.2. The impact of KMTs on business units' performance

This sub-section presents the second part of our model, represented in Fig. 1. The objective is to analyze how increasing reliance on KMTs affects firm performance. In particular, we are interested in analyzing both the direct and the indirect impact of KMTs on business units' financial performances. Direct impact is expected to occur through the improvement of knowledge-based

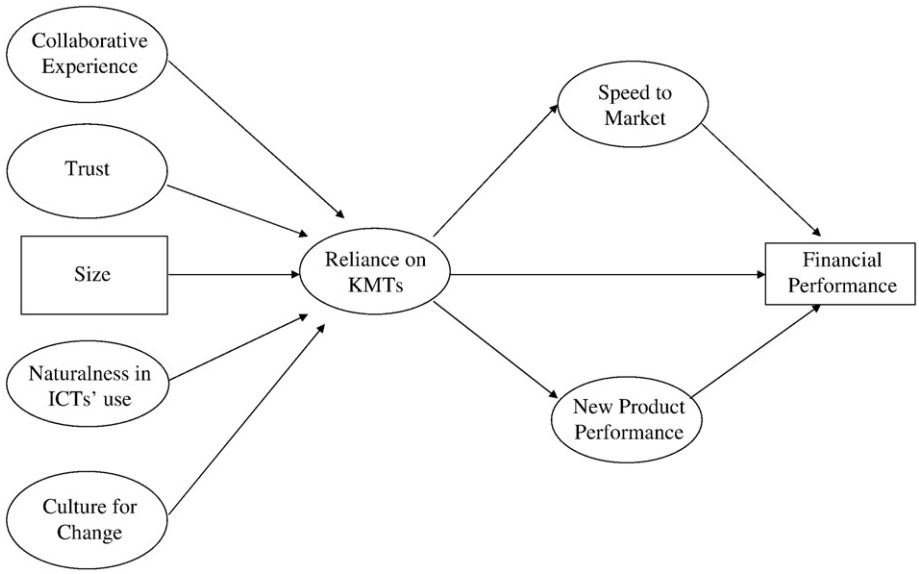

Fig. 1. Model 1: Chi-Square/d.o.f = 447/206, GFI = 0.75, CFI = 0.81, RMSEA = 0.10 (* = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$).

activities. The indirect impact is expected to be mediated by two innovation-related variables, i.e. product performance and speed to market in new product development.

Tanriverdi [2] has shown in the context of multi-business firms that intense knowledge management activities have a direct impact on firm financial performances due to the exploitation of knowledge-based synergies between business units. In inter-firm collaborations, the use of KMTs can impact financial performance in at least four ways. First, it can improve the easiness and reduce the costs of information transfer [1,2]. Second, it can reduce the costs caused by the loss of important information [5]. Third, KMTs can favor information sharing concerning R&D activities, and in turn they can reduce the risk of useless replications of innovation attempts and experiments [6]. Fourth, KMTs can reduce the lead times and costs associated with the implementation of new procedures and processes [36].

Thus, we expect that those business units that have a more intense use of KMTs will have better financial performances:

H5. Higher levels of reliance on KMTs will be positively associated with higher levels of financial performance of the business unit.

One of the critical characteristics of the innovation process is the need for an active combination of people, knowledge and resources [16,17,37]. For example, in a study of 72 technology firms, Smith et al. [38] demonstrated that the rate of new product and service introduction is a function of the organization members' ability to combine and exchange knowledge. Similarly, Obstfeld [18] shows with a multi-method study of an automotive R&D project that integration and connection of different knowledge sources, through the development of both dense social networks and diverse social circles, support an effective organizational involvement in innovation. We expect KMTs to play a role in enabling a business unit to improve its access and exchange of different internal and external knowledge sources as well as its ability to leverage them, leading to a positive impact on its innovative capability. It is worth mentioning that KMTs for data storage and transfer are relatively easier to use than other virtual technologies such as CAD software of crash test simulation software. Consequently, increasing levels of reliance on KMTs are expected to directly support better product performances through the improvement of knowledge-based processes of R&D activities. Thus, we suggest that:

H6. Higher levels of reliance on KMTs will support higher levels of new product performance.

Research has extensively documented that the adequate exploitation of virtual tools for the integration of operations management processes can be instrumental in supporting the reduction of production and transportation lead times along the supply chain (e.g. [39,40]). In the same way, KMTs, when compared with traditional working methods (i.e. paper-based tools), should allow easier and faster processes of transmission and development of technological knowledge in the context of inter-firm collaborations. The integration of knowledge-based assets can result in a reduction of bottlenecks and delays associated with new product development [40,41], enabling faster outcomes. Based on the above arguments, we propose that:

H7. Higher levels of reliance on KMTs will support faster speed to market in new product development.

The impact of new product development activities on financial results has been a controversial issue, in particular in mature sectors where innovations are mainly incremental and consequently the cost of innovation can overcome the relative gains related to product differentiation (e.g. [11,12,18,42,43]). Cooper and Kleinschmidt [44] show that new product superiority in terms of

features, innovativeness, and functional performance is a key factor differentiating winning and losing firms. Brown and Eisenhardt [45] state that new products that better fit market needs and requirements will provide higher financial returns. We consequently expect that superior new product performance, especially in terms of fulfillment of market requirements and the provision of high levels of quality, will enable superior firm financial performance. Based on the above arguments, we propose that:

H8. Higher levels of new product performance will support higher levels of firm financial performance.

Time-based competition [36] has become an important concern for contemporary business organizations. Firms recognize that quick response of competitors to new product introductions poses an important competitive threat [46] and, therefore, attempt to develop products even more quickly. This leads to spiraling rates of change and innovation in an industry [47]. Higher speed to market, understood as the ability to develop and launch new products in the market with lower lead times, guarantees quicker responses to market forces [19] which in turn should improve firm financial performance [48]. Consequently, we expect that faster speed to market will lead to better financial performance. Based on the above arguments, we suggest that:

H9. Faster speed to market will lead to higher levels of firm financial performance.

Fig. 1 presents the model with the nine hypotheses and the control variable represented by firm size.

3. Research method

3.1. Sample and data collection

As already introduced, the empirical setting of this study is the automotive sector, and in particular, inter-firm R&D projects between first and second-tier suppliers. We identified inter-firm R&D projects in the automotive sector as a very suitable context for our analysis for at least three reasons. First, KMTs have the potential to improve the effectiveness of most activities developed in these collaborative relationships because they can help to overcome temporal and geographical distances between individuals and groups [5,26]. Second, product innovation projects in the automotive sector are mainly based on inter-firm collaborations [44]. Finally, as already noted, a gradual process of standardization of operation activities driven by efficiency programs such as quality certifications, means that competition and financial success in the automotive sector is increasingly related to innovation capabilities [49].

This study focuses on the relationship between first and second-tier suppliers. The reason for this focus, instead of addressing the collaboration between first-tier suppliers and OEMs, are the results of previous works (e.g. [50,51]), which report that OEMs often impose their suppliers, not only the adoption of specific ICT tools, but also very strict routines for their use. In other words, the analysis of the use of KMTs in OEM — first-tier supplier relationships would have basically revealed the variations in the use of virtual tools as driven by OEMs. This would have two undesired effects. First, it would not be possible to analyze spontaneous uses of KMTs driven by a set of organizational factors. Second, previous research has pointed out that the forced adoption and use of ICTs into an organization do not guarantee an optimal use of these technologies and in turn better ICT-driven performances [5,52–55]. In other words, the procedures imposed by an OEM can be an exogenous force driving a sub-optimal use of KMTs of those business units of a first-tier supplier that are collaborating with that OEM. Moreover, recent research has showed that inter-firm collaboration between first and second-tier suppliers is critical for the innovation development of the automotive sector. While first-tier suppliers are expected to craft technologies and products to OEMs' needs, second-tier suppliers are very often responsible for the development of new technologies and processes that can be in turn used by the automotive sector [9]. In this context, the use of KMTs can be very important for two reasons. First, second-tier suppliers are very often distant from OEMs and that first-tier suppliers are generally located in clusters [9]. As a consequence KMTs can help to overcome the barriers of the geographical distance. Second, business units of second-tier suppliers are very often organized according to technologies instead of markets (e.g. automotive, aero spatial, etc.). These differences can cause delays, misunderstandings and other problems in the collaborative relationships between business units of first-tier suppliers, mainly working in the automotive sector, and business units of second-tier suppliers. KMTs can consequently be very helpful in reducing these problems by facilitating more frequent and effective knowledge-based interactions.

Since no published comprehensive data were available with the information associated with the constructs necessary to test our hypotheses, this study adopts the survey method to collect primary data on a population of Brazilian automotive first-tier suppliers. The unit of analysis is the business unit level. [56]

Among others the questionnaire requested information concerning: main corporate features (e.g. number of employees, and sales volume), the relationships with second-tier suppliers (e.g. level of trust, and habits in sharing technical problems), degree of usage of KMTs and other ICT tools in the relationship with second-tier suppliers, product performance, speed to market in the development of new products and financial performances, etc.

During the preliminary phases of the research we conducted an extensive literature review in order to search for existing constructs and scales suitable for our study. We then developed Likert-type measurement scales for the constructs associated to our conceptual framework following prior work that analyzed and measured the phenomena of our interest. Wherever possible, items were reused, or the general question format from existing scales was maintained. However, it was difficult to apply existing scales in their entirety. The development of the new items was also informed by field studies, as part of a broader qualitative

research by one of the authors, which included semi-structured interviews with managers and executives working in the supplier sector of the automobile industry in Brazil. In addition, one expert in this industry at the University of São Paulo, a scholar of an European R&D organization and two managers working in the R&D divisions of two automotive OEMs helped refine key constructs and measures. Finally, after the conclusion of the survey, we performed an *ex post* sorting test, i.e. we asked 9 experts of automotive R&D projects to associate each of our questionnaire items with one of the latent variables of our model. Each latent variable, as reported in the following section of the article, was described in the sorting test questionnaire using previous definitions of the literature. Moreover, at the end of the sorting test, we asked each expert to verify if any latent variable was measured with completeness and consistency through the measures they have previously selected. All 9 experts associated each item with the latent variable it was expected to measure and confirmed that each latent variable was measured with consistency and completeness through the questionnaire items.

The analysis, comparison and triangulation of insights from the literature review, interviews with scholars and practitioners and the sorting test, provide our constructs and their associated scales with content validity [46].

Before deciding on the final version of the questionnaire, we extensively pre-tested a preliminary version with executives in charge of manufacturing facilities at firms located in Brazil. After we had decided on the final version of the questionnaire, it was translated into Portuguese and then translated back into English to assure that the translation had not missed the meaning of any question. Following Dillman [57] the entire questionnaire was kept as short as possible in an attempt to increase the response rate. In addition, to minimize the potential for retrospective biases, we followed the strategy used in previous studies (e.g. [58]) of hiding the real objective of our investigation. We mailed the refined questionnaire in hard copies to those identified as the sample group, along with a personalized cover letter.

We identified our sample of automobile manufacturers and auto suppliers through the lists provided by ANFAVEA (the Brazilian Automobile Manufacturers Association) and by SINDIPECAS (the Brazilian Automobile Suppliers Association). In addition, we cross-checked the two associations' lists with the Brazilian magazine *Automotive News*, which is published once a year and profiles firms and executives in the auto industry in Brazil. After combining these data sources and deleting duplicated entries, we mailed the questionnaire to the remaining sample of 493 business units in the automobile industry of Brazil. We mailed the survey to senior managers responsible of productive plants or business units. After the initial mailing, a total of 37 questionnaires were returned because of incorrect addresses, which reduced the sample size to 456 business units. After two follow-ups, we received 136 usable questionnaires for a response rate of 27%. We excluded all business units declaring to be involved only in assembling activities and this selection of our population reached a total of 113 usable questionnaires. All 113 respondents held executive positions (e.g., plant manager, manufacturing supervisor, purchasing manager, etc.) and were directly involved in making important strategic decisions related to R&D activities for their respective business units. Moreover, we checked for the skewness and kurtosis of all items in our database to assess the normality of data distribution. All items show a skewness value between $+/-2$ and kurtosis inferior to 2 times the value of the standard deviation, as suggested by the previous literature (e.g. [67,68]). As a consequence, the conditions necessary to assume normality are met.

An important methodological concern of this study regards the reliability of the data gathered through the questionnaire-based survey. We addressed this issue by taking into account three main concerns: (1) non-response bias that might lead to a systematic exclusion of firms from the population; (2) common method variance and (3) validity of responses of a single key informant. Detailed information concerning how we addressed the aforementioned reliability issues is available in Appendix A of the text.

3.2. Operationalization of variables and construct validation

The validation of constructs – intended in the context of this research as reflective measures ([59]) – was developed through confirmatory factor analysis. We used confirmatory factor analysis instead of exploratory factor analysis because if "*hypotheses about plausible model structures exist, then exploratory factor analysis can frustrate attempts to test these ideas*" ([60], p. 228). Moreover, we tested the internal reliability of the scales through the Cronbach's Alpha, the composite reliability index (CRI) and the extracted variance index (EVI). We found that the three indexes associated with each latent variable were superior to the thresholds suggested by the previous literature, i.e. Cronbach's Alpha and CRI superior to 0.70 (e.g. [60–64]) and (EVI) superior to 0.40 [63].

We adopted aggregate means of the items associated with firm financial performance as its summary factor measure, in accordance to previous empirical researches (e.g. [54]). Below we provide the measurement indicators for the dimensions adopted in our structural model along with their reliability indexes.

We used multi-item measures to represent all the variables using a 5-point scale [2,6] – i.e. 1 = Strongly Disagree, 2 = Disagree Somewhat, 3 = Neither Agree nor Disagree, 4 = Agree Somewhat, 5 = Strongly Agree – with some items adapted from those used in similar studies (e.g. [65,66]). We used a 5-point scale for "Speed to Market" that was as follows: 1 = much slower, 2 = slower, 3 = about the same, 4 = faster, 5 = much faster. By the same token we adopted the following scale to test "New Product Performance": 1 = much lower, 2 = lower, 3 = about the same, 4 = better, 5 = much better.

The following are the measures for the constructs used in our study:

Collaborative experience. Consistent with the previous studies (e.g. [31,32]), we refer to collaborative experience as the firm's degree of previous experience in inter-firm collaborations. We measured the level of collaborative experience using the following three items (Cronbach's $\alpha = 0.89$, EVI = 0.75, CRI = 0.90): (1) our business unit has long history developing collaborative arrangements, (2) collaboration and partnership are a common practice in our business unit, and (3) we have engaged in many successful collaborative arrangements and alliances.

Culture for change. Consistent with the previous literature (e.g. [9,58]) we define culture for change as the readiness of an organization to accept modifications in working methodologies and procedures, and to creatively resolve new problems. We measured the level of creative and innovative culture using the following three items (Cronbach's $\alpha = 0.71$, EVI = 0.48, CRI = 0.73): (1) we reward people for updating our common methodologies and procedures, (2) in general, our people accept change readily, and (3) people in our business unit are encouraged to solve problems creatively.

Naturalness in the use of ICTs as an alternative way to face-to-face interactions. Consistent with the previous literature (e.g. [69,70]), we define "naturalness in the ICT use" as the bent to use virtual tools in substitution to face-to-face contacts. We measured the degree of this variable using the following three items (Cronbach's $\alpha = 0.80$, EVI = 0.49, CRI = 0.71): (1) the relationship between our product development staff and our major suppliers is characterized by a considerable teleconferencing contact, (2) the relationship between our product development staff and our major suppliers is characterized by a considerable desktop video-conferencing contact, and (3) the relationship between our product development staff and our major suppliers is characterized by a considerable telephone contact.

Mutual trust. Following the previous work (e.g. [71–73]) we refer to mutual trust as one party confidence that other parties will behave in a predictable and mutually acceptable manner. We measured the level of mutual trust using the following three items (Cronbach's $\alpha = 0.86$, EVI = 0.69, CRI = 0.87): (1) our business relationship with our major suppliers is characterized by a high level of trust, (2) we generally trust our major suppliers to stay within the terms of the contract, and (3) our major suppliers never try to alter the facts in order to get concessions from us.

Reliance on knowledge management tools. As already introduced, consistent with the previous literature [14,27], we refer to KMTs as those ICT applications that are implemented with the aim of managing and improving the knowledge-based assets of organizations. Given the empirical context of this study, we focus on the use of those electronic tools that support a) the development of electronic knowledge bases and, b) that guarantee standard procedures for knowledge transfer. We measured usage/reliance in knowledge-based software using the following three items (Cronbach's $\alpha = 0.79$, EVI = 0.65, CRI = 0.84): (1) our product development engineers and technical staff maintain an electronic knowledge base used by our suppliers, (2) our suppliers maintain an electronic knowledge base used by our product development engineers and/or technical staff and (3) our people follow standard procedures and rely on electronic systems for transferring knowledge across projects and business units.

It is worth mentioning that this procedure overcomes the identification problems that can be caused by the focus on specific technologies (e.g. groupware, mailing lists, etc.) [5]. Indeed, since there is a variety of KMTs that can serve to the aforementioned objectives, we decided to focus on the two critical features that are of our interest: a) the technological base of the processes that are software/electronic driven b) the ontological nature of the activities, i.e. knowledge storage/sharing and knowledge transfer.

Financial performance. We measured financial performance using four items (Cronbach's $\alpha = 0.90$, EVI = 0.70, CRI = 0.90). In the last 12 months, our business unit's performance measured by: (1) profitability, (2) return on investment (ROI), (3) return on sales (ROS), and (4) overall financial performance, has been better in comparison to our three major competitors.

Speed to market. Consistent with the previous literature (e.g. [19,20]) we refer to speed to market as the ability to develop and launch in the market new products with lower lead times and fast responses to the market. We measured speed to market using three items (Cronbach's $\alpha = 0.83$, EVI = 0.62, CRI = 0.83). In the last 12 months, in comparison to our three major competitors: (1) our time to determine the feasibility of proposed technologies was …, (2) our time to determine the plan for product development and introduction was …, (3) the overall speed to market of our products from initial idea to the occurrence of initial sales was ….

New product performance. Consistent with the previous literature (e.g. [9,55]) we refer to new product performance as the reputation – in terms of quality and overall performances – a new product has established after its introduction in the market. We measured new product performance using three items (Cronbach's $\alpha = 0.74$, EVI = 0.50, CRI = 0.75). In the last 12 months, in comparison to our three major competitors: (1) overall new product performance was …, (2) new product reputation was …, and (3) our overall level of new product quality has been.

4. Results

This study adopted the structural equation model in Fig. 1 to test hypotheses 1 to 9. Model 1 (Chi-Square = 447.14, d.o.f. = 206), shown in Fig. 1, tested all hypotheses predicted in Section 2. It confirms that collaborative experience (i.e. H3, $\beta = 0.376$, $p < 0.001$) and naturalness in using tools alternative to face-to-face relationship (i.e. H2, $\beta = 0.409$, $p = 0.001$) have a significant impact on the reliance on KMTs. On the contrary, culture for change (H1, $\beta = 0.120$, $p = 0.134$) and mutual trust (H4, $\beta = 0.087$, $p = 0.393$) do not have any statistical significance in explaining KMT reliance. As expected, the control variable firm size, expressed as logsales, is found to be significant (i.e. $\beta = 0.116$, $p = 0.07$).

As predicted, reliance on KMTs positively affects relative product performance (H6, $\beta = 0.142$, $p = 0.069$), speed to market (H7, $\beta = 0.315$, $p = 0.011$) and firm financial performance (H5, $\beta = 0.482$, $p = 0.001$).

Finally, model 1 suggests that relative product performance has a positive impact on firm financial performance (H8, $\beta = 2.127$, $p < 0.043$) while speed to market does not (H9, $\beta = -0.574$, $p = 0.225$) (Table 1).

We iteratively deleted trust (model 2, Chi-Square = 314.3, d.o.f. = 149; GFI = 0.79, IFI = 0.84, RMSEA = 0.10 and CFI = 0.84), and culture for change (model 3, Chi-Square = 193.6, d.o.f. = 100; GFI = 0.85, IFI = 0.91, RMSEA (LO90) = 0.07 and CFI = 0.90)

Table 1
Results model 1 (Chi-Squares = 447.14, d.o.f. = 206, n = 113, GFI = 0.75, CFI = 0.81, RMSEA = 0.10).

Outcomes	Predictor	Hypothesis	Standard estimate	Critical ratio	Standard error	p
Reliance on KMTs	Culture for change	H1	−.129	.086	−1.500	.134
Reliance on KMTs	Naturalness in ICTs' use	H2	.409	.125	3.286	.001
Reliance on KMTs	Collaborative experience	H3	.376	.088	4.283	****
Reliance on KMTs	Mutual trust	H4	.087	.102	.854	.393
Financial performance	Reliance on KMTS	H5	.482	.149	3.237	.001
New product performance	Reliance on KMTS	H6	.142	.078	1.821	.069
Speed to market	Reliance on KMTS	H7	.315	.123	2.558	.011
Financial performance	New product performance	H8	2.127	1.052	2.021	.043
Financial performance	Speed to market	H9	−.574	.473	−1.213	.225

controlling the significance of Chi-Square/d.o.f. ratio variations [71] and the fit indexes. The deletion of the relationship between speed to market and firm financial performance (model 4, Chi-Square = 197.5, d.o.f. = 131; GFI = 0.84, CFI = 0.89, and IFI = 0.90) does not provide any statistical improvement to fit indexes. On the contrary, the CFI and the IFI have a small decrease. As a consequence we choose as final model the number 3 whose results are presented in Fig. 2, Tables 2 and 3.

In the final model, the standardized factor loadings of measurement items on their related factors show a $p<0.001$ providing support for convergent validity [2,6]. The Chi-Square (193.6)/d.o.f. (100) ratio is inferior to 3 and the other incremental fit indexes, i.e. CFI, IFI, GFI and RMSEA respect the indications of the previous literature (e.g. [50,51]) (Tables 2, 3 and 4).

The results of the model offer important perspectives for a better understanding of the impact of KMTs on the effectiveness of inter-firm R&D efforts and on the role that organizational factors play in such context. First, they show that naturalness in using ICTs as substitutive way to face-to-face contacts ($\beta = 0.247$, $p = 0.016$) and collaborative experience ($\beta = 0.564$, $p<0.001$) have a positive impact on the degree of usage of ICT tools. However, mutual trust and innovative culture do not.

The second critical result of the analysis relates to impact of the usage of KMTs on firm performance. Results suggest that higher levels of reliance on KMTs are directly associated with higher financial performance ($\beta = 0.482$, $p = 0.001$), new product performance ($\beta = 0.126$, $p = 0.05$) and faster innovative capabilities ($\beta = 0.291$, $p<0.005$), as measured by speed to market. Moreover, there is an indirect contribution of KMTs to firm financial performance through the improvements of new product performance. Its total factor is $\beta = 0.265$. In contrast, the relationship between the speed to market and firm financial performance, the second indirect relationship predicted by our model, is not supported.

Finally, our model also shows that critical firm characteristics have an indirect effect on new product performance and speed to market variables through their influence on the use of KMTs. Thus, the naturalness in using ICTs as a substitution to face-to-face contacts, as well as collaborative experience has a statistically significant indirect impact of on new product performance with values of 0.016, 0.03 and 0.07, respectively. Their impact on speed to market performance is 0.037, 0.07 and 0.16.

5. Discussion, contributions and limitations

5.1. Contributions to the literature and perspectives for further research

This study contributes to literature along several dimensions. First, it extends previous studies that analyzed the relationships between organizational variables and the use of KMTs in inter-firm collaboration (e.g. [11–14]). In particular, it posits a set of theoretical constructs and provides quantitative empirical tests on the existence of favorable organizational conditions affecting

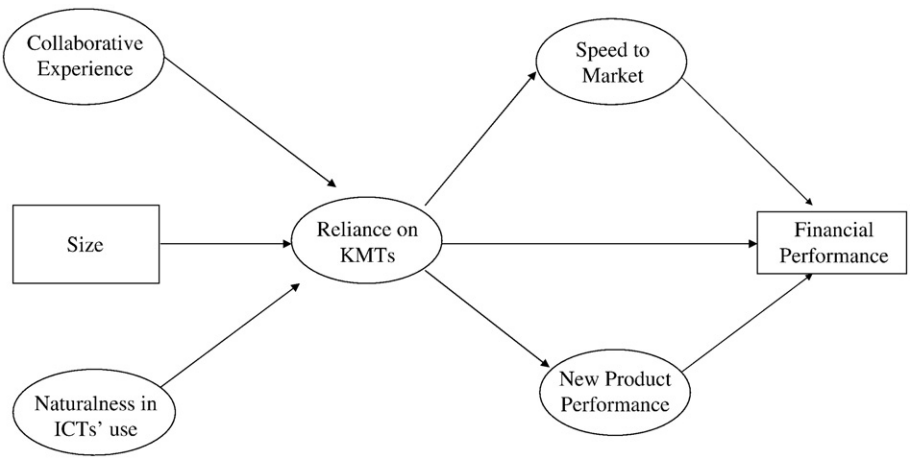

Fig. 2. Model 3: Chi-Square/d.o.f = 193.6/100; TLI = 0.92; IFI = 0.90; CFI = 0.90; GFI = 0.85 (* = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$).

Table 2
Results model 3 (* = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$) (Chi-Square = 193.6; d.o.f. = 100; $n = 113$; TLI = 0.92; IFI = 0.90; CFI = 0.90; GFI = 0.85; RMSEA (LO90) = 0.07).

Outcomes	Predictor	Hypothesis	Standard estimate	Critical ratio	Standard error	p
Reliance on KMTs	Naturalness in ICTs' use	H2	.247	.102	2.414	.016
Reliance on KMTs	Collaborative Experience	H3	.564	.119	4.728	****
Financial Performance	Reliance on KMTS	H5	.460	.123	3.741	****
New product performance	Reliance on KMTS	H6	.126	.065	1.955	.051
Speed to Market	Reliance on KMTS	H8	.291	.103	2.837	.005
Financial performance	New product performance	H8	2.106	1.043	2.019	.044
Financial performance	Speed to market	H9	−.558	.470	−1.186	.236

the use of KMTs in the context of inter-firm collaboration. The conclusions are that the naturalness in using ICTs as a substitution to face-to-face contacts and collaborative experience influence positively the degree of usage of ICT tools, while mutual trust and innovative culture do not.

The lack of a positive relationship between KMTs usage and mutual trust is important because it contradicts previous empirical studies. Although the importance of trust has been shown in different organizational contexts such as collaborative virtual efforts in business schools [74], or telemedicine collaborative projects [75], this work represents the first empirical investigation that analyzes its role in the context of inter-firm R&D collaboration. Thus, results suggest that virtual relationships can be affected by different organizational variables at intra- and inter-firm levels. In fact, the difference in results can potentially be explained by the particular role played by ICTs, and in particular KMTs, in inter-firm R&D relationships. Various authors (e.g. [74–76]) have suggested that the lack of trust between individuals interacting through ICTs can reduce the effectiveness of virtual knowledge-based exchanges supporting the exploitation of alternative methods of interaction such as face-to-face meetings. But, in the context of inter-firm relationships, ICTs frequently represent the *only* source of information due to the geographical delocalization of partners. Consequently, the reliance on KMTs is not conditioned by the trust variable because these tools can represent the only way to overcome the spatial and temporal constraints of a collaborative project between geographically dispersed R&D groups.

Another interesting result of this study concerns the missing relationship between the use of KMTs and the culture for change variables. As already stated, some studies (e.g. [43]) have pointed out that a lack of cultural attitude for change at the organizational level can deter the implementation and exploitation of ICTs in support of R&D activities. Our results instead suggest that R&D groups do not perceive KMTs as novel technologies. Indeed, at least in our example, R&D groups were composed by young highly skilled engineers that did not consider KMTs as new technologies. This indication confirms some research predicting a change in individual perceptions on the novelty of ICTs as the generations shift [77]. We found an interesting indication of such a trend during one of the interviews conducted at the beginning of our project where a junior engineer stated: "I am still waiting the day my company will finally implement web-based databases like those I created more than two years ago to share photos with my friends… here we are in the Paleolithic yet." We believe that this insight is very important because it points out the need to distinguish between ICT tools that are recognized as novel technologies and those tools that are already assimilated by individuals and organizations.

Further empirical research should explore the existence of other organizational variables (e.g. average employees' education level, or role of leaders in support of ICT-enabled processes) that can also affect the reliance of KMTs in the context of inter-firm collaborations and their related impact on firm innovative performance. Future research ought also to compare and contrast the different roles that other organizational variables may play on the use of KMTs at inter- and intra-firm levels. This would allow reaching more systematic conclusions as to the differences, commonalities and complementarities between the two environments.

Table 3
Factor loadings model 3 (* = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$).

Item	Latent variable	Estimate	Critical ratio	p
CE1	Collaborative experience	1.000		
CE2	Collaborative experience	.936	9.151	****
CE3	Collaborative experience	1.083	8.003	****
MN1	Naturalness in ICTs' use	1.000		
MN2	Naturalness in ICTs' use	1.308	4.487	****
MN3	Naturalness in ICTs' use	.780	4.222	****
KM1	Reliance on KMTS	1.000		
KM2	Reliance on KMTS	.652	3.904	****
KM3	Reliance on KMTS	1.285	9.769	****
SM1	Speed to market	1.000		
SM2	Speed to market	1.316	6.973	****
SM3	Speed to market	1.058	5.950	****
NP1	New product performance	1.557	5.489	****
NP2	New product performance	1.320	5.134	****
NP3	New product performance	2.106	2.019	**

Table 4
Correlation matrix of the variables of model 3.

	D	Mn1	Mn2	Mn3	Km1	Km2	Km3	Ce1	Ce2	Ce3	Np1	Np2	Np3	FP	Sm2	Sm3
D																
Mn1	0.1398															
Mn2	0.2030	0.4139														
Mn3	0.2448	0.5269	0.2124													
Km1	0.3271	0.3114	0.4200	0.3662												
Km2	0.3087	0.3903	0.6310	0.2709	0.6686											
Km3	0.3362	0.4238	0.4750	0.4913	0.4480	0.5339										
Ce1	0.2612	0.2688	0.4238	0.1789	0.2944	0.3053	0.3513									
Ce2	0.1403	0.2042	0.3900	0.1435	0.2788	0.3866	0.3714	0.8152								
Ce3	0.1941	0.3437	0.4893	0.3493	0.4052	0.4919	0.4445	0.7011	0.7793							
Np1	0.2366	0.0460	0.1506	0.1839	0.2622	0.1511	0.2440	0.1488	0.1627	0.2155						
Np2	−0.1086	0.2245	0.0327	0.1621	−0.0325	0.0052	0.1339	0.1643	0.2873	0.2190	0.2872					
Np3	0.0469	0.1463	−0.0119	0.3467	0.1007	−0.0486	0.1461	0.1208	0.1082	0.1506	0.3978	0.5177				
FP	−0.1163	0.1026	0.1318	0.0740	0.1634	0.1620	0.1008	0.3229	0.3618	0.3157	0.3197	0.3398	0.3841			
Sm2	−0.0083	0.0724	0.0186	0.2885	0.0071	−0.0536	0.1829	0.0981	0.1603	0.1790	0.1714	0.3417	0.3295	−0.0808		
Sm3	0.1407	0.1613	0.0471	0.0589	−0.0325	−0.0587	0.0301	0.2246	0.1971	0.1311	0.2872	0.2911	0.2626	0.2127	0.0749	
Sm1	0.1885	0.3059	0.1961	0.4433	0.1925	0.0993	0.3527	0.2388	0.2402	0.3629	0.3845	0.3736	0.3283	0.1433	0.4648	0.2610

A second important contribution of this study concerns the impact of KMTs on innovation performances of R&D groups. This study confirms the previous qualitative research that showed the positive impact of KMTs on innovative activities through the improvement of knowledge-based processes (see, e.g. [10,37]). In particular, this study provides evidence supporting the critical role played by knowledge sharing and knowledge transfer in new product performance and speed to market for inter-firm collaborations in mature industries. These results complement the work by Haas and Hansen [78,79], which found that the use of electronic documents had a limited impact on the outcomes of sales offers prepared by consulting firms. Yet, it sheds light on two important novel issues. First, the outcomes of KMTs can be different according to the sector/market or the activities carried out by a business unit. Indeed, the impact of knowledge-based activities such as knowledge creation and knowledge re-use is different in relation to the area of business, the technological sector and the type of activities conducted by individuals and groups. For example, knowledge re-use has proven to be critical for innovation processes in the context of modular technologies [6]; but, it can be less important in other contexts such as consulting, where identifying customers' requests and expectations is a key variable. Second, the empirical context of this study is a mature sector where innovation-related variables play a critical role for financial success. Further research should take into account this important finding and further explore on the specificities of other sectors and functional areas to improve our understanding of the opportunities offered by KMT-driven processes.

A third contribution of this study is improving our understanding of the impact of KMTs on the financial performance of business units involved in R&D inter-firm projects. We find that higher levels of reliance on KMTs have a positive influence on new product performance and product development cycle time, as well as an indirect influence on financial performance through improved product performance. Moreover, contrary to several previous studies, this paper shows that the intensive use of KMT has a direct positive influence on business units' financial performance. We believe that a key factor explaining why we do observe such direct relation lies in the object of our research effort. While previous literature typically analyzed the relationships between ICTs, knowledge management issues and firm performances in an intra-firm perspective (e.g. [2,8,54]), this study looks at the direct and innovation-mediated impact of KMTs' use on business units' financial performances in the context of inter-firm collaboration. It is a very favorable environment to study these relations because ICTs have the potential to improve these collaborative relationships by helping to overcome temporal and geographical distances between individuals and groups. A complementary implication of these results is that, while some categories of ICTs, such as electronic data interchange systems, have the potential to improve firm financial performance through the improvement of operational activities [55], others, including KMTs, can have a similar positive effect in supporting better innovation performance. Finally, it is also relevant to try to understand the lack of a relation between new product development speed and firm performance. We believe this can happen for two reasons. The first is related to the long lead time associated with the creation of new automotive products, more than 5 years, and the fact that, in a market such as Latin America, vehicles are commercialized some time after being launched in other major markets. As a result, the market might not reward faster R&D teams. A second possible explanation is that, given the rather strict contractual agreements currently stipulated in sectors like the automotive, suppliers have to address the timing expectations of their clients. As a consequence, timing is not a factor that can provide a distinctive differentiation because clients are capable to impose the lead times they need to their suppliers.

A fourth contribution of this study is the observation that at least three organizational conditions have an indirect impact on innovation and firm financial performance through the use of KMTs. This is an important result because it helps to better understand the overall mechanisms leading to successful inter-firm innovation collaborations and the related role of KMTs. Further research should look at synergies associated with KMT-enabled integration between operational and innovation processes.

Finally, the results also confirm and extend previous methodological indications related to the measurement of organizational ICT-enabled processes and their impact on firm performance. In particular, studies have suggested that empirical research should

avoid considering ICT as a "*single factor*" [5,39]. Our study confirms this important methodological indication. In particular, it suggests that it is necessary to take into account the different roles played by IT applications in intra and inter-firm relationships. Our results show that the intensive use of KMTs can directly affect firm performance by allowing, not only the creation of knowledge-based synergies with partners, but also the quick acquisition of important information from the environment, which in turn leads to faster responses to market trends and needs. Further research should take into account this important methodological issue by analyzing the organizational mechanisms through which different IT-tools add the value of intra and inter-firm activities.

5.2. Contributions to practice

The findings of this work also open new perspectives for managerial practice. First, managers of R&D inter-firm projects should consider and adequately develop systems and organizational routines in order to exploit the opportunities offered by KMTs in support of knowledge-based exchanges. Our work suggests that the adoption and exploitation of KMTs are particularly suitable when improvements in the innovativeness and speed of new product development are relevant. Moreover, a more intense use of KMTs has both a direct and indirect (innovation-mediated) positive effects on firm performance. The development of organizational routines driving more intense uses of KMTs is consequently expected to support better financial performances.

Second, the evidence on the importance of several critical organizational variables affecting the use of KMTs has at least two implications for practitioners. First, it can help managers understand specific conditions that favor the exploitation of KMTs and, consequently, offer them guidance on decisions that can create a better environment to support improvements in inter-firm collaboration. Moreover, it can drive some additional selection criteria for hiring and/or selecting new personnel to be involved in inter-firm R&D collaborations. For example, our results suggest that teams where individuals have previous collaborative experience and use more naturalness in using virtual technologies in substitution of face-to-face meetings are more likely to sustain better innovation outputs through the exploitation of KMTs. However, these indications should be considered with some caution since the empirical setting of this study was the business unit and consequently any generalization at lower unit of analysis, such as individuals or small groups, need further empirical scrutiny.

5.3. Limitations

This study has some limitations that should be taken into consideration, especially due to the fact that the empirical analysis is based on a population of Brazilian automotive first-tier supplier respondents. This empirical setting, which is very interesting to analyze innovation activities of firms localized in developing countries that intend to compete in mature industries, has also some drawbacks. First, the specific feature of the automotive sector can affect some of the results of the study. We can expect, for example, that more dynamic markets (e.g. nanotechnologies, and computer hardware) might show different results in what concern the relationship between variables such as speed to market and financial performances. Second, the automotive first-tier supplier sector in Brazil has shown an important progress in terms of improving its innovative competitiveness over the last decade [9]. Yet, Brazilian suppliers are currently competitive in R&D activities associated mostly to "established technologies" (e.g. mechanics, and molds). As a result, our study provides limited indications on the impact of KMTs in innovative processes in new high-value technological domains such as automatic controls or composite materials. Third, Brazilian first-tier suppliers collaborate mainly with technological partners that are geographically dispersed [47]. This feature reflects the recent trend of progressive geographical delocalization of R&D activities in multinational companies. But there are several other areas where physical proximity is still a critical issue. Thus, our study provides limited indications of the impact of KMTs in inter-firm collaborations where individuals that are located in the same geographical area adopt virtual technologies.

Another important limitation is the fact that this study provides only a snapshot in time. Several authors (e.g. [4,5,39]) suggest that the analysis of the impact of ICTs on firm performances should be based on panel data and in particular when their empirical setting concerns adoption analysis. While this study is focused on the use of ICTs and not on adoption issues, our cross-sectional dataset does not allow any estimation of eventual variations along the time between the use of KMTs and their expected impact on firm innovation and financial outputs.

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Appendix A

An important methodological concern of this study regards the reliability of the data gathered through the questionnaire-based survey. We addressed this issue by taking into account three main concerns: (1) non-response bias that might lead to a systematic

exclusion of firms from the population; (2) common method variance [80, 81] and (3) validity of responses of a single key informant.

In order to minimize the potential problems above introduced, we developed a specific strategy of data processing. First, we evaluated non-response bias using the Armstrong and Overton's procedure [81]. In order to ascertain non-response bias across the survey instrument itself, we performed *t*-tests comparing early and late respondents. The first 70% of the returned questionnaires were defined as early responses and the remaining 30% as late responses and thus deemed representative of firms that ultimately did not respond to the survey. We performed *t*-tests on all variables to compare early and late responses. We found no significant differences between early and late respondents on any one of the selected variables, suggesting that non-response bias would not likely exist in the survey instrument.

Although Malhotra et al. [82] have recently shown that common method variance in IS research is not an important concern as found in other disciplines, we developed a two-step strategy in order to address this issue. First, the questionnaire was prepared taking into account the main causes of common method variance, i.e. common rater effect, item characteristic effect, item context effect and measurement context effect [80]. For example, we avoided social desirability effects [83] – an important component of common rate effect [80, 83] – explaining in the questionnaire introduction that: a) the survey was developed with the aim to develop a quantitative study and not to make judgments on individuals and/or institutions, b) questionnaire responses were not linked to the identity of the respondent or to the name of the company where the respondent was employed and c) data would be treated with strict confidentiality in accordance with the ethical norms of our sponsoring institutions. We also avoided item ambiguity [84] – an important component of item characteristic effect [80, 84, 85] – through the pretest of the questionnaire with a large number of executives working in the Brazilian automotive sector. Pretests were indeed very useful since they provided useful insights for the improvement of item clarity.

After the completion of the survey, we performed as *ex post* control of the final database, the Harman's one-factor test. Neither a single factor from the factor analysis nor a general factor in accounting for the covariance of independent and criterion variables emerged in our analysis as a confirmation of the lack of common method variance disturbances [85].

We also developed a specific strategy to reduce the incorrect answers caused by the use of a single informant response. First, informants were asked questions related to their current production method and inter-firm collaborative relationships. Prior research suggests that informant recollections are stable over short periods of time [86]. Second, we used the field studies, conducted as part of another study by one of the authors in conjunction with plant tour observations, and the literature review to verify respondents' consistency and reliability. Finally, we compared informants' responses to archival and public data (e.g., company profiles and articles from the business press) where available. These comparisons provided a check that the informants were accurate and competent sources and we did not keep out any questionnaire from our database due to reliability concerns.

Table A1
Standard CFA measurement model (* = $p<0.10$; ** = $p<0.05$; *** = $p<0.01$; **** = $p<0.001$).

Latent variable	Item	Estimate	Standard error	Critical ratio	*p*
Collaborative experience	CE1	1.000			
	CE2	0.761	0.113	6.717	****
	CE3	0.786	0.124	6.349	****
Naturalness in ICTs' use	MN1	1.000			
	MN2	1.127	0.326	3.455	****
	MN3	0.858	0.239	3.586	****
Reliance on KMTs	KM1	1.000			
	KM2	0.762	0.164	4.650	****
	KM3	0.621	0.162	3.827	****
Speed to market	SM1	1.000			
	SM2	0.373	0.139	2.679	***
	SM3	0.994	0.162	6.122	****
New product performance	NP1	1.000			
	NP2	0.839	0.129	6.516	****
	NP3	0.660	0.135	4.895	****
Financial performance	FP1	1.000			
	FP2	0.866	0.122	7.746	****
	FP3	0.922	0.114	8.162	****
	FP4	1.004	0.115	8.747	****
Trust	TR1	1.000			
	TR2	0.990	0.112	8.811	****
	TR3	1.112	0.120	9.250	****
Culture for change	CC1	1.000			
	CC2	0.860	0.130	6.631	****
	CC3	1.136	0.184	6.181	****

References

[1] R. Sabherwal, S. Sabherwal, Knowledge management using information technology: determinants of short-term impact on firm value, Decis. Sci. 36 (4) (2005) 531–567.
[2] H. Tanriverdi, Information technology relatedness, knowledge management capability, and performance in multibusiness firms, MIS Q. 29 (2) (2005) 311–344.
[3] M.C. Anderson, R.D. Banker, S. Ravindran, Value implications of investments in information technology, Manag. Sci. 52 (9) (2006) 1359–1376.
[4] E. Brynjolfsson, S. Yang, Information technology and production: a review of the literature, Adv. Comput. 43 (1996) 179–214.
[5] H.C. Lucas, Information Technology and the Productivity Paradox, Oxford University Press, Oxford, 1999.
[6] A. Vaccaro, F. Veloso, S. Brusoni, The impact of virtual technologies on knowledge-based processes: an empirical study, Res. Policy 38 (8) (2009) 1278–1287.
[7] H. Tanriverdi, Performance effects of information technology synergies in multibusiness firms, MIS Q. 30 (1) (2006) 57–77.
[8] I. Álvarez, R. Marin, Antonio Fonfría, The role of networking in the competitiveness of firms, Technol. Forecast. Soc. Change 76 (2009) 410–421.
[9] M. Kotabe, R. Parente, J. Murray, Antecedents and outcomes of modular production in the Brazilian automotive industry: a grounded theory approach, J. Int. Bus. Stud. 38 (1) (2007) 84–106.
[10] M.C. Becker, P. Salvatore, F. Zirpoli, The impact of virtual simulation tools on problem-solving and new product development organization, Res. Policy 34 (9) (2005) 1305–1321.
[11] J. Bento, J.P. Duarte, T.V. Heitor, M. Heitor, Remote Collaborative Design: Case Studies of Transatlantic Cooperation in Engineering and Architecture, in: J. Bento, J.P. Duarte, M. Heitor, W.J. Mitchell (Eds.), Collaborative Design and Learning, Praeger, Westport, 2004.
[12] U. Cantner, K. Joel, T. Schmidt, The use of knowledge management by German innovators, J. Know. Manag. 13 (4) (2009) 187–203.
[13] L.C. Chi, W. Holsapple, Understanding computer-mediated inter organizational collaboration: a model and framework, J. Know. Manag. 9 (1) (2005) 53–75.
[14] M.D. Alavi, D. Leidner, Knowledge management and knowledge management systems: conceptual foundations and research issues, MIS Q. 25 (1) (2001) 106–127.
[15] S.A. Furst, M. Reeves, B. Rosen, R.S. Blackburn, Managing the life cycle of virtual teams, Acad. Manag. Exec. 19 (2) (2004) 6–20.
[16] B. Kogut, U. Zander, Knowledge of the firm, combinative capabilities, and the replication of technology, Organ. Sci. 3 (3) (1992) 383–397.
[17] J.S. Brown, P. Duguid, Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation, Organ. Sci. 2 (1) (1991) 40–57.
[18] D. Obstfeld, Social networks, the Tertius Iungens orientation, and involvement in innovation, Adm. Sci. Q. 50 (2005) 100–130.
[19] C.H. Fine, Clockspeed: Winning Industry Control in the Age of Temporary Advantage, Perseus, Reading (MA), 1998.
[20] K.B. Clark, T. Fujimoto, Product Development Performance: Strategy, Organization and Management in the World Auto Industry, Harvard Business School Press, Boston (MA), 1991.
[21] L. D'Adderio, Crafting the virtual prototype: how firms integrate knowledge and capabilities across organisational boundaries. Res. Policy 30 (9) (2001) 1409–1424.
[22] L. D'Adderio, Configuring software, reconfiguring memories: the influence of integrated systems on the reproduction of knowledge and routines. Ind. Corporate Change 12 (2) (2003) 321–350.
[23] K. Henderson, Flexible sketches and inflexible data bases: visual communication, conscription devices, and boundary objects in design engineering. Sci. Technol. Hum. Values 16 (4) (1991) 448–473.
[24] E. Cacciatori, Memory objects in project environments: storing, retrieving and adapting learning in project-based firms, Res. Policy 37 (9) (2008) 1591–1601.
[25] A.M. Aladwani, Change management strategies for successful ERP implementation, Bus. Process Manag. 7 (3) (2001) 266–275.
[26] F. Santos, The role of IT for knowledge management in firms, Int. J. Technol. Policy Manag. 3 (2) (2003) 194–203.
[27] T.H. Davenport, L. Prusak, Working Knowledge: How Organizations Manage What They Know, Harvard Business School Press, Boston, 1997.
[28] N. Selwyn, Apart from technology: understanding people's non-use of information and communication technologies in everyday life, Technol. Soc. 25 (2003) 99–116.
[29] P. Chapman, M. James-Moore, M. Szczygiel, D. Thompson, Building internet capabilities in SMEs, Logistics Info. Manag. 13 (6) (2000) 353–361.
[30] M.A. Lyles, Learning among joint venture sophisticated firms, Manag. Int. Rev. 28 (special issue) (1998) 85–98.
[31] B. Simonin, The importance of collaborative know-how: an empirical test of the learning organization, Acad. Manag. Rev. 40 (5) (1997) 1150–1174.
[32] W. Powell, K.W. Koput, L. Smith-Doerr, Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology, Adm. Sci. Q. 41 (1996) 116–145.
[33] S. Ghoshal, P. Moran, Bad for practice: a critique of the transaction cost theory, Acad. Manag. Rev. 21 (1) (1996) 13–47.
[34] C. Handy, Trust and the virtual organization, Harv. Bus. Rev. 73 (3) (1995) 40–50.
[35] R.T. Hightower, L. Sayeed, M.E. Warkentin, R. McHaney, Information Exchange in Virtual Work Groups, Idea Group Publishing, Hershey (PA), 1997.
[36] G. Stalk, Time — the next source of competitive advantage, Harv. Bus. Rev. 66 (1998) 41–51.
[37] W.C. Bogner, P. Bansal, Knowledge management as the basis of sustained high performance, J. Manag. Stud. 44 (1) (2007) 165–188.
[38] K.G. Smith, C.J. Collins, K.D. Clark, Existing knowledge, knowledge creation capability and the rate of new product introduction in high-technology firms, Acad. Manag. J. 48 (2) (2005) 346–357.
[39] T. Mukhopadhyay, S. Kekre, S. Kalathur, Business value of information technology: a study of electronic data interchange, MIS Q. 19 (2) (1995) 137–156.
[40] J. Jayaram, S.K. Vickery, C. Droge, The effects of information system infrastructure and process improvements on supply-chain time performance, Int. J. Phys. Distrib. Logistics Manag. 30 (3/4) (2000) 314–330.
[41] S.C. Wheelwright, K.B. Clark, Revolutionalizing Product Development: Quantum Leaps in Speed, Efficiency, and Quality, The Free Press, New York, 1992.
[42] D. Teece, Profiting from technological innovation: implications for integration, collaboration, licensing and public policy, Res. Policy 15 (6) (1986) 285–305.
[43] D. Teece, Managing Intellectual Capital: Organizational, Strategic and Policy Dimensions, Oxford University Press, Oxford, 2002.
[44] R. Cooper, E.J. Kleinschmidt, New products: what separates winners from losers? J. Prod. Innov. Manag. 4 (3) (1987) 169–184.
[45] S.L. Brown, K. Eisenhardt, Product development: past research, present findings and future directions, Acad. Manag. Rev. 20 (2) (1995) 343–378.
[46] D. Bowman, H. Gatignon, Determinants of competitor response time to a new product introduction, J. Market. Res. 32 (1) (1995) 42–53.
[47] E.D. Hahn, R. Parente, The Supply Chain and New Products: a Clockspeed Perspective, Presented at the Decision Science Meeting, Boston, 2004.
[48] A. Barua, P. Konana, A. Whinston, F. Yin, Driving e-business excellence, MIT SLOAN Manag. Rev. 43 (1) (2001) 36–44.
[49] B. Dyck, F.A. Starke, G.A. Mischke, M. Mauws, Learning to build a car: an empirical investigation of organizational learning, J. Manag. Stud. 42 (2) (2005) 387–416.
[50] D. Mackay, The impact of EDI on the components sector of the Australian automotive industry, J. Strateg. Info. Syst. 2 (3) (1993) 243–263.
[51] V.K. Tuunainen, Opportunities of effective integration of EDI for small businesses in the automotive industry, Info. Manag. 34 (6) (1999) 361–375.
[52] P. Palvia, D.B. Means, W.M. Jackson, Determinants of computing in very small businesses, Info. Manag. 27 (3) (1994) 161–174.
[53] S.H. Thomke, Capturing the real value of innovation tools, MIT SLOAN Manag. Rev. 47 (2) (2006) 24–32.
[54] M. Tippins, R. Sohi, IT competency and firm performance: is organizational learning a missing link? Strateg. Manag. J. 24 (8) (2003) 745–761.
[55] J. Jayaram, S.K. Vickery, C. Droge, The effects of information system infrastructure and process improvements on supply-chain time performance, Int. J. Phys. Distrib. Logistics Manag. 30 (3/4) (2000) 314–330.
[56] M. Malhotra, V. Grover, An assessment of survey research in POM: from constructs to theory, J. Oper. Manag. 16 (4) (1998) 407–425.
[57] D. Dillman, Mail and Telephone Surveys: The Total Design Method, Wiley, New York, 1978.
[58] R.L. Stump, J.B. Heide, Controlling supplier opportunism in industrial relationships, J. Market. Res. 33 (4) (1996) 431–442.
[59] J.R. Edwards, R.P. Bagozzi, On the nature and direction of relationships between constructs and measures, Psychol. Methods 5 (2) (2000) 155–174.
[60] K.A. Bollen, Structural Equations with Latent Variables, Wiley, New York, 1989.

[61] R.B. Kline, Principle and Practice of Structural Equation Modeling, Guilford Press, New York, 1998.
[62] J.C. Nunnally, Psychometric Theory, 2nd ed.McGraw-Hill, New York, 1978.
[63] J.F. Hair, R.E. Anderson, R.L. Tatham, W.C. Black, Multivariate Data Analysis, Prentice-Hall, Englewood Cliffs, 1995.
[64] H. Mendelson, R. Pillai, Industry clockspeed: measurement and operational implications, Manufactur. Serv. Oper. Manag. 1 (1) (1999) 1–20.
[65] N. Worren, (2001). Creating dynamic capabilities: The role of modular product and process architectures. Unpublished doctoral dissertation, Said Business School, Oxford University.
[66] N. Worren, K. Moore, P. Cardona, Modularity, strategic flexibility and firm performance: a study of the home appliance industry, Strateg. Manag. J. 23 (12) (2002) 1123–1140.
[67] M. Porter, M. Fuller, Coalitions and Global Strategy, in: M. Porter (Ed.), Competition in Global Industries, Harvard Business School Press, Boston, 1986, pp. 315–343.
[68] A. Saxenian, Regional Advantage, Harvard University Press, Boston, MA, 1994.
[69] Barki Henri, Hartwick Jon, Measuring User Participation, User Involvement, And User Attitude, MIS Quarterly 18 (1) (1994) 59–83.
[70] John S. Edwards, Duncan Shaw, Paul M. Collier, Knowledge management systems: finding a way with technology, Journal of Knowledge Management 9 (1) (2005) 113–125.
[71] D.M. De Rosa, D.A. Hantula, N. Kock, J. D'Arcy, Trust and leadership in virtual teamwork: a media naturalness perspective, Hum. Resour. Manag. 43 (2–3) (2004) 219–232.
[72] P.M. Doney, J.P. Cannon, An examination of the nature of trust in buyer–seller relationships, J. Mark. 61 (4) (1997) 5–51.
[73] J.B. Barney, M.H. Hansen, Trustworthiness as a source of competitive advantage, Strateg. Manag. J. 15 (1994) 75–190 Special issue Winter.
[74] Piccoli, B. Ives, Trust and the unintended effects of behavior control in virtual teams, MIS Q. 27 (3) (2003) 365–395.
[75] D.L. Paul, R.R. McDaniel, A field study of the effect of interpersonal trust on virtual collaborative relationship performance, MIS Q. 28 (2) (2004) 183–227.
[76] J.C. Guan, C.K. Mok, R.C. Yam, T.K.S. Chin, K.F. Pun, Technology transfer and innovation performance: evidence from Chinese firms, Technol. Forecast. Soc. Change 73 (2006) 666–678.
[77] L. Floridi, A look into the future impact of ICT on our lives, Info. Soc. 23 (1) (2007) 59–64.
[78] M.R. Haas, M.T. Hansen, When using knowledge can hurt performance: the value of organizational capabilities in a management consulting company, Strateg. Manag. J. 26 (1) (2005) 1, 24.
[79] M.R. Haas, M.T. Hansen, Different knowledge, different benefits: toward a productivity perspective on knowledge sharing in organizations. Strateg. Manag. J. 28 (11) (2007) 1133.
[80] P.M. Podsakoff, S.B. MacKenzie, L. Jeong-Yeon, N.P. Podsakoff, Common Method Biases in Behavioral Research: A Critical Review of the Literature and Recommended Remedies, Journal of Applied Psychology 88 (5) (2003) 879–903.
[81] J.S. Armstrong, T.S. Overton, Estimating nonresponse bias in mail surveys, Journal of Marketing Research 14 (3) (1977) 396–402.
[82] N.K. Malhotra, S.S. Kim, A. Patil, Common Method Variance in IS Research: A Comparison of Alternative Approaches and a Reanalysis of Past Research, Management Science 52 (12) (2006) 1865–1883.
[83] D.C. Ganster, H.W. Hennessey, F. Luthans, Social desirability response effects: Three alternative models, Academy of Management Journal 26 (2) (1983) 321–331.
[84] R.A. Peterson, *Constructing effective questionnaires*, Sage, Thousand Oaks, CA, 2000.
[85] P.M. Podsakoff, D.W. Organ, Self-reports in organizational research: Problems and prospects, Journal of Management 12 (4) (1986) 531–544.
[86] P.H. Huber, Temporal Stability and Response-Order Biases in Participant Descriptions of Organizational Decisions, The Academy of Management Journal 28 (4) (1985) 943–950.

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